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EFFECTS OF DISPLAY FRAMES OF REFERENCE ON SPATIAL JUDGMENTS AND CHANGE DETECTION

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Technical Report ARL-00-14/FED-LAB-00-4

September 2000

Prepared for

U.S. Army Research Laboratory
Interactive Displays Federated Laboratory

Contract DAAL 01-96-2-0003

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **EFFECTS OF DISPLAY FRAMES OF REFERENCE ON SPATIAL JUDGMENTS AND CHANGE DETECTION**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Research Laboratory,Aberdeen Proving Ground,MD,21005**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**74**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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ABSTRACT

In the present experiment, we compared three types of computer-generated displays of battlefield information in order to address the possible influence of any of four potential causes of display-induced cognitive tunneling, which had been found in the Immersed display condition of Thomas, Wickens, & Merlo, 1999. First, it is possible that information within the initial 90° forward field of view (FFOV) of the 3-D egocentric view in the Immersed display suite acquired too much salience, and information outside the FFOV was overlooked. Second, it is possible that the Immersed participants were simply not using the manual panning function to view the entire 360° of the environment because of the information access cost associated with it, and thus never seeing information outside of the initial FFOV. Third, it is possible that there was simply too much information to store in working memory in the amount of time taken to complete each scene, which resulted in some relevant information never getting encoded. Finally, it is possible that Immersed participants were not accurately integrating information across the two views provided in the display.

Participants viewed one of three types of displays of battlefield information and were asked to make spatial judgments, provide counts of visible enemy units, detect changes to these enemy units, and select paths through the environment. The Tethered display is equivalent to the one used in Thomas et al (1999). However, there were two versions of the Immersed display in this experiment; the first (self-pan) allowed participants to actively pan the environment (similar to the Immersed condition used by Thomas et al), while the second (auto-pan) automatically panned the environment as the participants observed passively.

Our findings suggest that Immersed participants who were provided with a manual panning feature actively panned the environment and produced performance levels equivalent to the Tethered group on most tasks, so the problem is not likely one of information access cost. However, the autopan group of Immersed participants tended to prematurely close the automatic panning feature prior to viewing all of the environment and in general produced poorer performance than either of the other two groups. Both of these Immersed groups failed to adequately obtain relevant information from the secondary 2-D inset map view provided in the display, suggesting that the performance difference as compared to the Tethered group was due to a failure of adequately integrating information across the two views of the Immersed display. Also, the salience of centrally located information appeared to affect the abilities of participants in all three display condition to detect changes; changes outside of the FFOV in the Immersed displays, or in the periphery of the Tethered display, were not detected as well as changes which were centrally located. In addition, participants in all three display conditions showed a drop in change detection performance as the number of changes per scene increased, which lends support to the hypothesis that working memory affects change detection. These results may be used to guide more effective design of battlefield information displays.

1. INTRODUCTION

1.1. Overview

As the Army begins to incorporate increasingly complex electronic displays in the command stations as well as on the battlefield, it is important to determine how best to present battlefield information so that it effectively supports the commander's goals. It is vital that the information presented on these displays is accurate and complete. In addition, the display format itself should not be a source of cognitive bias and should allow for easy access of the information. This information allows the commander to visualize the battlefield and, based on this "battlefield visualization," the commander forms hypotheses which are the bases for selecting courses of action (Department of the Army, 1997). Any deficiencies in acquiring and interpreting the battle information can affect the commander's decision-making processes and jeopardize the subsequent choice of courses of action (COAs).

Battlefield visualization (BV) is a fundamental part of a military commander's decision-making capability. BV requires several types of information: terrain information, friendly and enemy troop locations and movements, and orientation and navigation-related information. Commanders must be able to extract information from multiple sources, integrate and interpret it accurately, and update it as necessary when the situation changes. In addition, commanders must also have the meta-cognitive ability to determine the completeness and accuracy of the information they have received in order to determine how much more information must be obtained to form a complete mental picture of the battlefield. If these computer-generated displays are intended to support BV, it is necessary that they provide comprehensive information to the commanders in a manner that facilitates information integration and acquisition. Additionally, the information must be displayed in a manner that does not inherently bias its interpretation or disguise changes to the information.

With current advances in display technology, many possible methods of presenting battlefield information become available. The observer's viewpoint, quality and quantity of data presented, and interactive display features can all be manipulated to produce a fantastic array of information. Our goal is to investigate what combination of these factors produces the battlefield display that best supports the commander's tasks in the field.

1.2. Frame of Reference Effects in Map Displays

In the study which directly preceded the research described here, we investigated the effects of several different frames of reference on navigation-related (orientation) tasks as well as on hazard awareness (Thomas, Wickens, & Merlo, 1999). Because the results of this study provide the impetus for the current investigation and the rationale for choosing the independent variables that will be manipulated, we describe this study in some detail, before reviewing the relevant literature. 30 West Point officers participated in the experiment and responded to questions requiring distance and direction judgments, counts of enemy units, and identification and change detection of enemy units in the area, while viewing the information from one of two different display frame of reference conditions.

Frames of reference (FORs) for the display viewpoint may be defined along three dimensions: egocentricity, vertical rotation, and lateral rotation, represented in Figure I1. The egocentric dimension specifies the extent to which the display viewpoint shows a view of the environment similar to that which an observer would see if he were actually in that environment. In Figure I1, cell A represents the egocentric, or "immersed," viewpoint while cells B through E represent increasingly exocentric viewpoints.

Once a viewpoint becomes exocentric (removed from the observer's point of view), vertical rotation becomes possible, which affects whether the display is two-dimensional (2-D) or three-dimensional (3-D). If the viewpoint is rotated up from the horizontal between 0° and 89° then the display will show a perspective view of the environment. If the viewpoint is rotated all the way to 90° then the elevation information fundamental to a 3-D perspective view is eliminated and the view becomes 2-D. Cells A, B, and C represent 3-D perspective views created by a vertical rotation within 0° and 89°, and Cells D and E represent the 2-D views resulting from a 90° vertical rotation.

Additionally, the exocentric FORs can have a fixed viewpoint or a laterally rotating viewpoint. (In an egocentric display the viewpoint orientation is assumed to always be slaved to the observer's viewing direction and therefore necessarily has lateral rotation.) A display with lateral rotation follows the observer's motion through the environment, generally orienting such that the observer's motion appears to be towards the top of the screen (track-up) with the environment moving relative to the stationary observer. Cells B and D are examples of exocentric FORs (3-D and 2-D respectively) with laterally rotating, or "tethered," viewpoints. A display with a fixed viewpoint shows the observer moving with respect to the stationary environment, which is generally oriented with north at the top of the screen (north-up). Cells C and E are examples of fixed-viewpoint exocentric 3-D and 2-D FORs, respectively.

In Thomas et al (1999), we created two displays which contained different FORs in order to evaluate how well each display supported a variety of orientation and hazard awareness tasks. The first display, "Tethered," consisted of a 3-D exocentric viewpoint, which showed the participant's position within the environment in the form of a small Army tank, as well as displaying areas to the sides and behind the tank. The vertical rotation was created by locating the viewpoint 3000 meters above and 1200 meters behind the tank's position, producing an angle of approximately 60°. This display also had lateral rotation such that for each scene, the tank appeared in the same position on the screen (centered in the lower third) while the environment moved with respect to it. The Tethered view had two orientation aids; a compass arrow located directly above the tank which always indicated due north to support direction judgments, and a 1-km bar located directly to the left of the tank to support distance judgments.

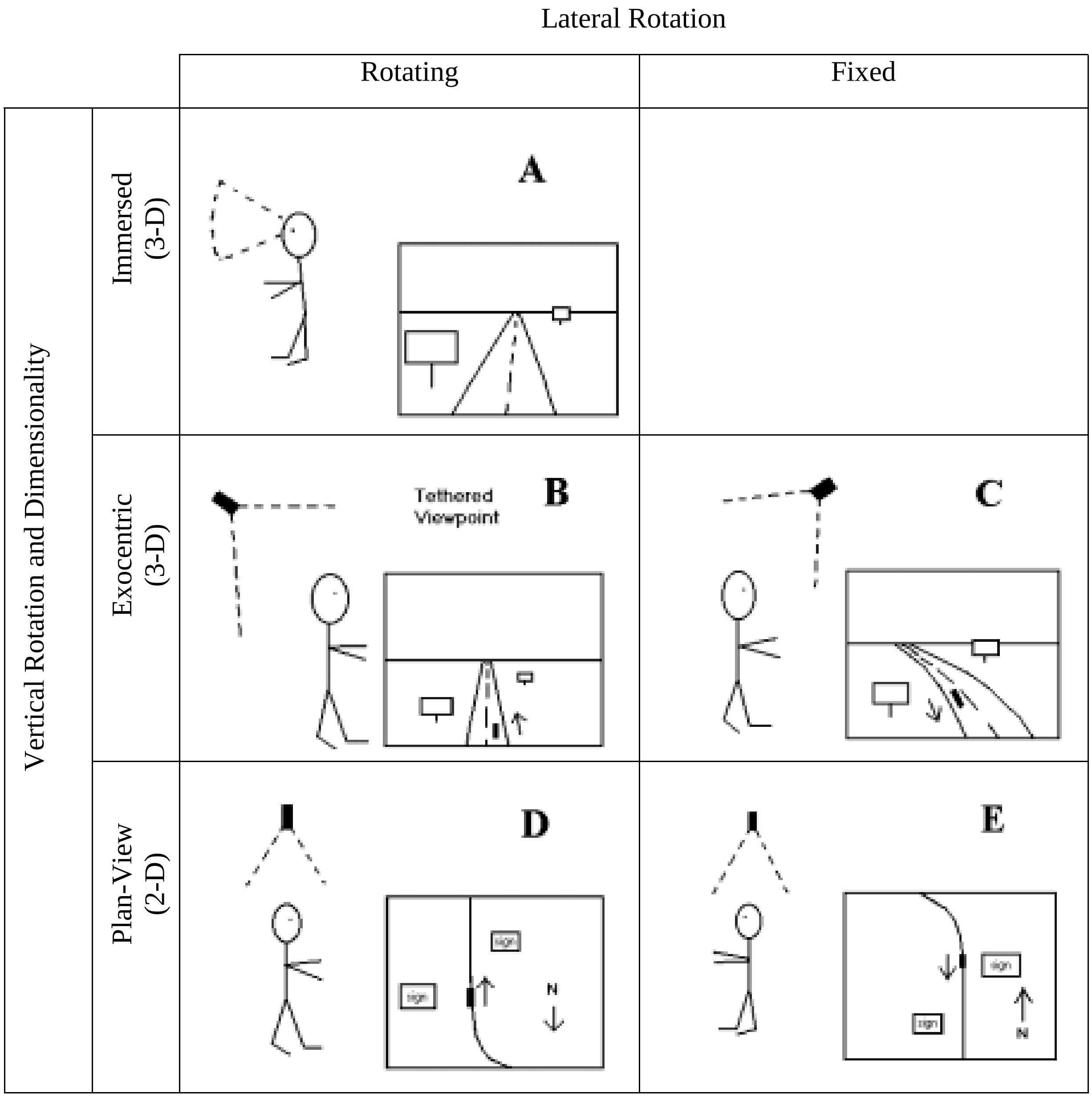


Figure I1. Features of Egocentricity of a Display. The three rows describe three different levels of vertical viewpoint location and rotation. The two columns describe two levels of lateral viewpoint rotation. The top three cells represent “3-D” or perspective displays, while the bottom two cells depict 2-D displays.

The second display, "Immersed," was actually composed of two different FORs. The primary FOR, which occupied most of the screen, was a 3-D egocentric view, which showed the environment as though the observer were standing in it looking around. Since only 90° horizontal of the environment could be displayed at any one time, participants could control the direction of the view by using the mouse buttons to pan the viewpoint to the left or right, though the entire 360° of the environment. The second FOR was a small 2-D north-up contour map located in the center of the top third of the screen. This view showed the entire area of interest, including the participant's location and a rotating wedge which indicated what part of the environment was currently being viewed in the 3-D egocentric view (Aretz, 1991). As the participant panned the environment, the wedge rotated in the corresponding direction, which helped keep the participant oriented to the correct direction and support direction judgments. In addition, a square grid was overlaid on the 2-D map, with each edge of the squares representing 10 km, to support distance judgments.

Enemy units were represented by red signposts marked with traditional Army symbols for size and type. The enemy units could be either "confirmed" (solid lines) or "unconfirmed" (dashed lines), depending on the validity of the information on which they were based. Both types of enemy units were visible in the Tethered condition and were potentially visible in the 3-D view of the Immersed condition if adequate panning was accomplished. However, only confirmed enemy units were visible (as small red dots) on the 2-D map in the Immersed condition. This feature was added because in several cases, confirmed enemy units which were visible in the Tethered view were obscured by terrain in the Immersed condition due to the lower vertical rotation angle of the viewpoint.

All information presented was equivalent between the two display conditions such that participants in both conditions should have been able to answer each question correctly. For the tethered view, all such information was directly available in the single display panel. For the immersed view, it could be either accessed in the initial forward view, by panning the view, or by consulting the small 2-D inset map. Figure I2 illustrates how the information was distributed to the two display types.

Participants observed 25 consecutive scenes of a tank (representing a battalion) progressing through a mountainous environment past enemy units. They were asked to perform two tasks during the scenes. The first task was to provide a verbal report of detected enemy units, including information on size, type, distance, and direction (relative to the tank's position), as well as any changes detected from one scene to the next. The second task was to respond to computer-based questions which required the participants to make judgments about distances and directions to specific objects within each scene, to provide counts of enemy units in each scene, and to make several other types of evaluations relevant to a battle scenario.

Immersed condition participants judged distances more accurately than Tethered, because of the inherent distortion caused by 3-D perspective foreshortening (Banks & Wickens, 1997; McGreevy & Ellis, 1986). Immersed participants were able to use the 2-D inset map to accurately gauge distances rather than relying on the 3-D perspective view. Both groups performed equally well on the direction judgments, which suggests that they were able to effectively use the direction aids (compass needle for Tethered condition, directional wedge on the 2-D north-up inset map for Immersed condition).

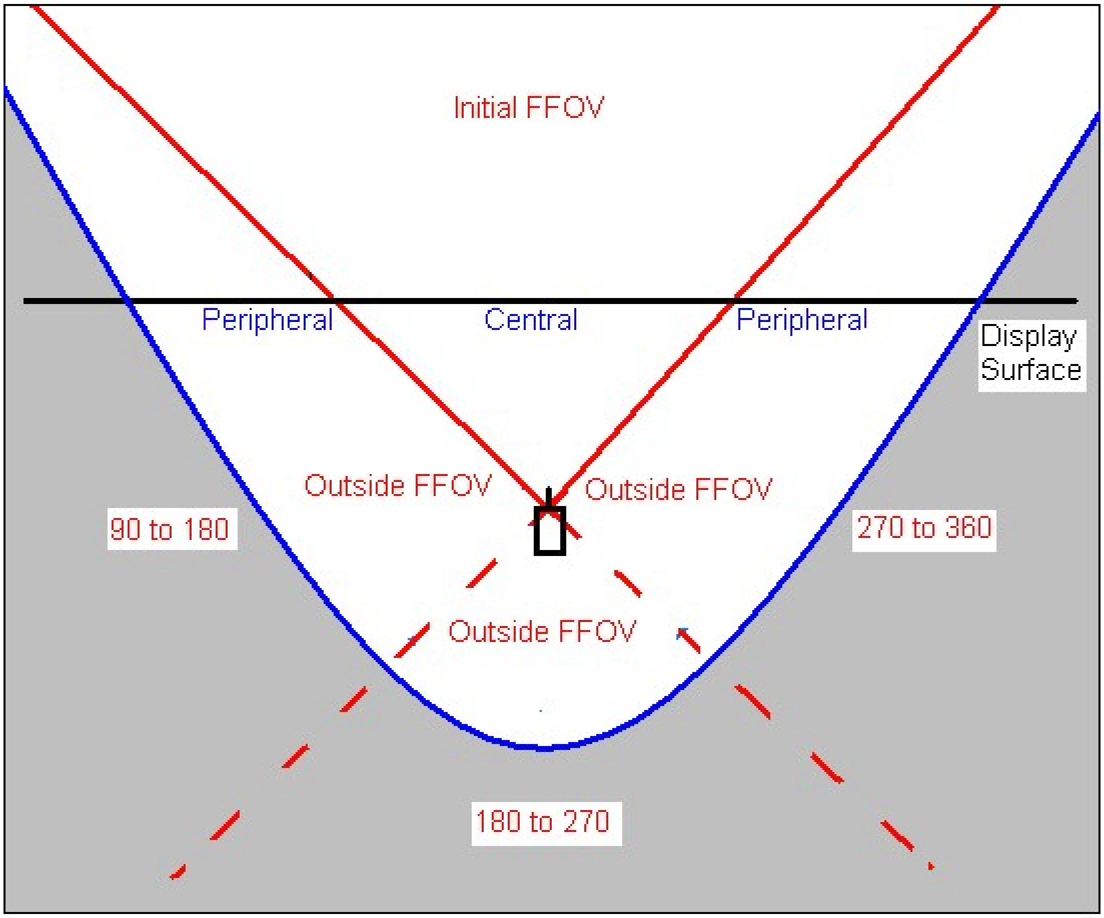


Figure I2. Schematic of the two display conditions. The V-shaped red lines represent the initial viewpoint of the Immersed display, with dashed-line extensions demarcating each 90° quadrant of the environment. The curved blue line represents the Tethered display's viewpoint, showing the area behind and to the sides of the tank's location. No information was placed in the shaded area, since it was not visible in both the Tethered and Immersed conditions simultaneously.

The result of particular interest for the current experiment was that the Tethered condition participants produced more accurate counts of visible enemy units than the Immersed participants. Further analysis suggested that Immersed participants may not have using the panning function adequately to acquire information that was outside the initial FFOV. To illustrate, their counts of enemy units tended to be lower than the actual number, indicating that they missed seeing one or two units that were located to the sides or behind their tank's position (i.e. outside the initial FFOV). In addition, analysis of several scenes provided evidence that Immersed participants may not have been accurately integrating information between the two views in the Immersed suite. However, Immersed participants' confidence ratings were uniformly high, equal to those of the Tethered participants, regardless of performance decrements. This suggests that the Immersed participants were satisfied with the information they acquired, even though it proved to be incomplete. Taken together, the lower performance on enemy count questions and high confidence suggest that Immersed participants were paying too much attention to information presented in the initial FFOV of the 3-D view in the suite display, ignoring or not seeing information located outside the FFOV and possibly ignoring information from the 2-D map as well.

Analysis of the tape-recorded verbal change detection reports further revealed that of 45 possible changes (from one scene to the next), 13 changes were identified by participants in the Tethered conditions, and only 1 change was detected by Immersed participants. Thus, although the overall reporting of detected changes for both groups was low, there was a significant difference between display conditions on change detection ability. Again, the performance difference was inferred to result from too much emphasis on initial FFOV information in the Immersed condition, causing these participants to miss changes to objects, especially those located outside the initial FFOV.

Thomas et al (1999) concluded that the poor enemy count performance and poor change detection in the Immersed condition were due to display-induced “cognitive tunneling,” which causes the observer to focus on initially presented information at the expense of other relevant information in the periphery (or not immediately available). In this case, the Immersed participants tended to use only that information which was available in the 3-D view’s initial FFOV. Those participants did not adequately gather that information, such as unconfirmed enemy units outside the FFOV (through subsequent panning) or confirmed units which were only visible on the 2-D map. It was not clear, however, what factors were causing the decrements to performance on change detection and counting visible enemy units in the Immersed condition, and whether these factors are limited strictly to the 3-D egocentric view or whether integration across the two views in the Immersed display suite was a significant factor. We propose three potential causes for the deficiencies of the 3-D egocentric view of the Immersed suite, which may be labeled salience, memory failure, and information access effort and are associated, respectively, with breakdowns in perception, memory, and response. In addition, we propose a fourth cause which is related to the integration of the two views (3-D egocentric and 2-D inset map) of the Immersed suite.

1. **Salience, or perceptual failure**: According to this hypothesis, some of the targets outside of the FFOV in the Immersed display were simply not noticed, even though they might have been scanned (i.e., passed through the field of view), because they were somehow deemed less important, or less prominent, than those encountered first, which were more salient. Performance differences between display conditions indicated that the lower performance in the Immersed condition was caused by primacy of the initial FFOV, or cognitive tunneling into the initial view while ignoring information from the periphery. If Salience was the primary cause of the performance decrements between Tethered and Immersed conditions, then we would expect to see evidence that the Immersed participants are panning the environment and presumably perceiving enemy unit information from outside the initial FFOV but not incorporating that information into their final responses.

2. **Information Access, or response, failure**: According to this hypothesis, participants who were allowed to manually control their viewpoint may not have noticed new items because they didn’t pan the environment adequately (if at all) and thus their viewpoint might not have passed over all of the relevant objects in the periphery. An important issue

in any interface design is the information access cost required to retrieve the necessary information (Wickens, Vincow, Shopper, and Lincoln, 1997). Visual scanning imposes some cost, head movement imposes greater cost, and, in many circumstances, interaction with a manual response device (such as the panning required here) imposes a still greater cost. Given the inherent tendency of users to conserve cognitive and physical effort, it can be hypothesized that users might not choose to adequately pan the environment, if they anticipate that the expected gain in information would not offset the cost of such effort, particularly under time pressure (Wickens & Holland, 2000). However, if observers were presented with the necessary information from panning automatically, with no demands on effort, then we would expect performance to be better in a condition such as this than in a condition where the information must be gathered by manual panning, especially if the participants were not put under any external time pressure.

3. **Working Memory failure**: According to this hypothesis, as the number of changes to objects between two consecutive scenes increased, it became harder for participants to remember where each target was on each preceding screen, and hence harder to remember whether each target in successive scenes had just appeared or had changed from the previous scene, or whether a target in a previous scene was no longer visible. If memory was the primary cause of the performance decrements, scenes with many changes would likely produce poorer overall change detection performance regardless of display type. Additionally, if memory was the culprit, it is likely that the effect of increasing memory load (more changes) would be more detrimental in the Immersed condition because Immersed participants were, to a greater extent than Tethered participants, presented with items in different locations in successive scenes, adding additional memory loads. That is, the increased memory load across different locations (panning views) should interact with the additional memory load of more complex changes.

4. **Dual-View Integration failure**: According to this hypothesis, participants in the Immersed condition were not able to accurately integrate information from both the 3-D egocentric view and the 2-D map view. If integration failure was the primary cause of performance differences between Immersed and Tethered conditions, then scenes that require participants to integrate information that is only available on the 2-D map (i.e. confirmed enemy units which are obscured by terrain in the 3-D view) with that in the 3-D view will produce poorer performance than scenes where participants can rely solely on information in the 3-D view, regardless of whether that information is inside or outside of the initial FFOV.

The current research describes a second experiment which was designed to evaluate each of these potential causes to determine which one(s) were the primary source of the performance decrements in the Immersed display condition. This experiment had three display conditions; a Tethered condition and an Immersed condition with manual panning, just like those display conditions employed in Thomas et al (1999), as well as a second Immersed condition, visually identical to the first Immersed condition but with an automatic-panning feature instead of voluntary manual panning. The tasks performed in this experiment were similar as well to Thomas et al (1999); participants judged distance and direction to enemy objects, provided counts of visible enemy objects, and reported perceived changes to objects. A new task in the current experiment was for participants to choose paths through the environment at several points during the experiment.

To explore the first three hypotheses, we compared performance on tasks which involve obtaining information from outside of the initial FFOV in the Immersed display (and from the periphery of the Tethered display) with performance on tasks where all of the information is present in the initial FFOV (or centrally located in the Tethered display). The relevant tasks for these comparisons are the judgments of number of visible enemy units, and change detection. We expect that if Salience is the primary factor in cognitive tunneling, performance will be lower for the former category of questions because of the dominance of the initial FFOV information in both of the Immersed conditions. We also expect that Salience will have a lesser effect in the Tethered condition because all of the information is presented at once. If Information Access failure is the primary factor, we expect that performance on these tasks, specifically on those questions which require outside-FFOV information, will be higher in an immersed condition which has an automatic-panning feature (thus eliminating the information access cost of manual panning) than in an immersed condition which requires manual panning. To the extent that Working Memory failure is causing the cognitive tunneling, we expect that there will be a decrease in performance as the number of changes per scene increases, across all three view conditions, and that this drop will be more prominent in the Immersed conditions because of the extra memory workload described above.

To explore hypothesis 4 (Dual-view Integration), we compared performance on (1) enemy count questions which require participants in the Immersed conditions to obtain information from both views within the display and integrate it correctly with (2) enemy count questions where all of the information is available in the 3-D view (regardless of whether it is in the FFOV or the periphery). It should be noted that the change detection task required only information within the 3-D view, thus no integration of information from the 2-D map was required to correctly detect changes. We expect that if Dual-view Integration failure is the primary cause of cognitive tunneling, then Immersed participants will perform more poorly on those tasks requiring information from both views than on the latter type of tasks. Tethered condition performance should be unaffected since there is only one view in the Tethered display and thus integration is not a factor.

1.3. Display Factors

In comparing a 3-D exocentric display with a suite display composed of a 3-D egocentric display and a 2-D contour map, we address three categories of factors affected either directly or indirectly by display frames of reference. First, there are basic perceptual factors, such as line-of-sight ambiguity and distance foreshortening. These factors, which affect 3-D perspective views, are evidenced whenever an observer has difficulty in making distance judgments, and are discussed in greater detail in Banks, Wickens, & Hah (1998). In the current experiment, it is hypothesized that these perceptual factors will affect how participants in each condition perceive and make spatial judgments about the terrain, and in turn will affect what paths they select when they are given the option to navigate through the environment.

Second, there are attention allocation factors, which are encountered in dual displays such as the Immersed suite display described above. When an observer gathers information from two or more views, the information must be integrated between the views in order to be interpreted. In addition, if those views have different FORs, then various mental manipulations must be performed in order to integrate the information across the views. The following examples illustrate the role of these attentional factors in terms of the four potential causes of cognitive tunneling described earlier. First, since each view is competing for the observer's attention, it is possible for one of these views to draw more of the observer's attention, especially if it is more eye-catching and immersive, thus increasing the salience of that view's information over information from other views. Second, since the observer cannot attend to all available views at once, there is a memory workload associated with remembering information from each view; information presented on only one view may be forgotten or changes to objects missed if the observer is not paying enough attention to that view. Third, if one or both of the views also have to be manipulated such that peripheral, but relevant, information becomes visible, accessing the information introduces a cost to the participant. And fourth, integrating information across two views that are simultaneously visible already taxes the mental workload; if each view's format is substantially different in terms of viewpoint FOR, scale, and presentation of information, integration across the views becomes even more difficult due to the requirement of mental rotation or manipulation of each view's information.

Last, cognitive factors, especially the biases affecting information access and information seeking, play a role in determining how successfully a display can be employed. Cognitive biases can affect the extent to which observers continue to seek out new information. For example, if the observer has high confidence that the information which is initially visible is complete, he/she will not seek out additional information, for example in the periphery of the environment (Cooper & Sniezek, 1998). This limitation could be attributed to each of the four potential causes of cognitive tunneling described above: either the high salience of the initially presented information, the fact that the participant may forget there may be relevant information in the periphery, or the fact that the participant may decide not to make the effort to extract further information. Alternatively, the participant may decide that sufficient information is available in the Immersed 3-D view and not seek information from the 2-D map view as well.

Each of these factors (perceptual, attentional, and cognitive) will be discussed in more detail below. In addition, past research on change detection will be reviewed in order to illustrate the importance of detecting changes as an independent variable in determining how each of the causes of cognitive tunneling affect performance on a relevant task.

1.3.1. <u>Basic perceptual factors</u>. Although flat (2-D) maps have traditionally been used in planning battlefield maneuvers, there is a significant amount of mental workload, as well as time cost, associated with converting traditional 2-D map feature symbology into meaningful three-dimensional terrain information (Aretz & Wickens, 1992; Wickens & Prevett, 1995). Computer-generated 3-D perspective displays can instantly provide terrain information in a format which most closely resembles the actual terrain as seen by an observer in the environment, minimizing the mental workload of interpreting 2-D maps (Banks & Wickens, 1997; Wickens & Prevett, 1995).

However, certain perceptual problems arise in a 3-D display which are affected by the vertical rotation of the eyepoint (see Figure I1 above). When the angle is relatively low (close to 0° vertical rotation, see cell A in Figure I1), elevation information within the scene is relatively undistorted, since it is seen from a side-view (more or less preserving the Z-axis, or elevation, information). However, the 3-D depth information is projected onto a 2-D display surface, and at this low vertical angle depth information is maximally compressed or "foreshortened" relative to the lateral and vertical information (Banks & Wickens, 1997). As the eyepoint rotation is increased through 45° vertical rotation (see cells B and C in Figure I1), producing a more downward viewing angle, depth information becomes more accessible (although still far from veridical), while vertical elevation information becomes increasingly compressed. Since both depth and elevation are distorted, this leads to misjudging altitude relative to distance, producing the effect that individual variations (such as hill slopes) in the displayed terrain appear to be steeper than they really are (Banks & Wickens, 1997; McGreevy & Ellis, 1986; Perrone & Wenderoth, 1993), although the **absolute** elevation information is still compressed. Finally, as the eyepoint's vertical rotation approaches 90°, horizontal information becomes veridical while elevation information is maximally compressed (cells D and E in Figure I1) and must be presented in an analog or symbolic form (such as contour lines or numerical information).

Wickens, Thomas, & Young (2000, experiment 1) illustrated that there is a perspective-based ambiguity when using a 3-D exocentric view to determine whether one object has a clear horizontal line-of-sight to another object, or to estimate distances between objects. In their experiment, participants viewed different computer-generated terrains on one of three display types: a 2-D plan-view display, a 3-D perspective display, or an interactive 3-D egocentric, immersed display. They found that line-of-sight judgments were answered most accurately, although with a time cost, when participants viewed the interactive 3-D immersed view (which subjects were able to manipulate to show different selected regions), since this view eliminated the mental transformations necessary to determine whether any elevated terrain was sufficient to obscure the line-of-sight by depicting the path of line-of-sight visually. However, distance estimations were best supported by the 2-D display of the environment, which provided the most accurate depth information.

In sum, a 3-D view can present horizontally fore-shortened or vertically compressed information, causing observers to misjudge distances and elevations, respectively. Since terrain analysis plays a large role for military commanders who are trying to determine possible routes for their troops, it seems critical to determine how terrain, especially mountainous terrain, is interpreted when presented in a 3-D display. Take the example of a battle commander using a 3-D display with a 45° vertical rotation to decide which of two routes to take through enemy territory. One route takes the troops closer to more enemy positions, but a mountain range is located between the troops and those enemy positions. The other route takes the troops near only a few enemy positions, but on open ground. Although the 3-D exocentric display would present the terrain information in such a way that the commander would recognize the mountainous region immediately (given the exaggerated slopes and features), the vertical compression effect might cause the commander to underestimate the absolute height of those mountains (compared to estimating the vertical information in a 3-D egocentric view), making the mountains appear to be less of an obstacle than they really are and thus judging the enemy behind them to be more of a threat. In addition, as Banks & Wickens (1997) found, the commander using a 3-D exocentric display may not be able to quickly and accurately determine whether the enemy has line-of-sight capabilities over the mountain tops due to the perspective nature of the display. Thus the commander might order his troops to take the other route, towards the small number of easily visible enemy on open ground, resulting in a certain conflict when the mountain route was actually safer and conflict-free. In the same situation, a commander referring to a 2-D display of the same environment would have more accurate elevation information (via contour lines or numbers) and be able to determine that the mountains safely shield the friendly troops from the enemy on the other side.

Therefore, it is of particular interest when creating displays for battle scenarios, to determine how the dimensionality of the viewpoint will affect terrain (and thus battlefield) visualization. We will address this question explicitly in the present experiment in the form of spatial judgments of distances and directions to enemy objects in the environment as well as allowing the participants to select a path from several options according to various battle-relevant criteria.

1.3.2. Attentional factors. Given the inherent perceptual problems of single FOR viewpoints described above, one solution is to combine several different viewpoints into one display to provide a more complete picture. Each view in a dual-view or multiple-view display can provide the information which is missing or distorted in another view, just as the 2-D contour map provided information that was distorted or not visible in the 3-D view of the Immersed display used in the study by Thomas et al (1999) described above. For example, a commonly used dual display is the coplanar display, which combines a 2-D overhead view, which lacks pictorial elevation information, with (typically) an orthogonal, side view which provides veridical elevation information (at the expense of depth information). Coplanar displays of this type have been found to support better (or at least equally good) vertical control and navigation when compared with 3-D perspective displays, which introduce distortions in both lateral and vertical information (Haskell & Wickens, 1993; Olmos, Wickens, & Chudy, 2000; Wickens, Liang, Prevett, & Olmos, 1996).

However, although dual-view displays are intended to mitigate the perceptual effects of single-FOR displays, and to some extent they do so, they also introduce new problems with attention allocation. When using a dual-view suite, participants have to be able to switch attention between the multiple views in order to gather information and integrate that information. In order for the compromise display to be considered effective, participants must be able to scan the multiple views effectively (e.g. to sufficiently detect changes in one or more of the available views). If, however, one of the multiple views is more “compelling” than the others, participants may pay too much attention to that one at the expense of gathering information from the other views. In this latter case, the other ignored views are not used to extract the additional information that was intended and the observer is said to be “cognitively tunneled” into the one view (Olmos et al, 2000).

Results of the experiments conducted by Olmos et al (2000), which compared a coplanar view with a dual display suite composed of a 3-D immersed (“pilot’s eye”) view and a 3-D exocentric (“global”) view, indicated that participants in the 3-D dual display condition tended to pay too much attention to the 3-D immersed view at the expense of detecting relevant hazard information in the 3-D exocentric view. Clearly a suite display containing distributed information is only useful in gathering complete information if participants attend to both (or all) views.

Also, there are the added costs of integrating information between two (or more) views which are different visually and in terms of relative scales of the environment shown within the views. The proximity compatibility principle (PCP) suggests that an effective multi-view display is one where the views with closely related information are located close together within the space of that display, thus minimizing the cost of information access between related views (Wickens, 1993; Wickens & Carswell, 1995). However, the PCP also recommends that, in order to minimize cognitive effort in integrating the information across related views, those views should be made mentally compatible as well as spatially compatible, by presenting the information in a format which is consistent (and thus more easily integrated) across the views (Wickens, 1993). While suite displays, such as the Immersed condition display used in Thomas et al (1999), present two collocated views with no clutter or distracter views (satisfying the PCP's spatial compatibility concept), the two views present terrain information with very different scales and frames of reference, which serves the purpose of providing more information about the environment than is available on one single view, but produces a cost of information integration. In Thomas et al (1999), it was proposed that the performance decrement in the Immersed condition (when compared to the Tethered condition) could be at least partially attributed to a problem with integration of the information presented on the two views of the Immersed display suite. Analysis of some of the scenes in Thomas et al provided evidence that Immersed participants were incorrectly integrating information from the two different views and basing their responses on this inaccurate perception of the information. An additional finding by Olmos et al (2000) was that there was an additional cost of integrating the information across the egocentric and exocentric views of the 3-D dual display because of the difference in FORs.

Finally, another potential problem with using dual display formatting is that some information is "hidden" and must be obtained through conscious effort by the observer. Research indicates that observers tend to conserve their efforts in information seeking (McCormick, Wickens, Banks, & Yeh, 1998). For example, when an immersed 3-D display (which consists of a limited horizontal field of view) presents that initial information and "hides" the rest of the environment (e.g. the "keyhole" effect, Woods, 1984), the initial information can draw the observer's attention and cause him/her to forget to scan the rest of the environment, which may contain additional relevant information (Olmos, Wickens, & Chudy, 2000; Thomas et al, 1999).

Thus the benefits of multiple sources of information must be compared to the costs of attention switching, cognitive tunneling, information integration and information access in order to determine whether a compromise display will be beneficial in a specific situation. To determine how great the costs of cognitive tunneling are, we now examine several cognitive decision-making biases associated with visual displays.

1.3.3. <u>Cognitive factors: Anchoring and overconfidence</u>. In addition to display formatting, cognitive factors play a role in determining how, when, and where attention is allocated in a visual display. When observers are using a display to gather information, it is important that they know what type of information to look for, where to look for it, how accurate the information is, and when their information is complete so they can terminate their search. In the context of a battlefield, these meta-cognitive abilities are essential for accurate battlefield visualization: commanders must be able to obtain and integrate information about the physical environment (terrain) as well as the locations and movements of enemy units within that environment. In addition, commanders must be able to determine how accurate their information is by constantly reviewing the displays, searching for any changes to existing information or any additional information.

However, this type of meta-cognitive information-gathering process has been found to be affected by several decision-making biases (Mosier, Skitka, Heers, & Burdick, 1998; Perrin, Barnett, & Walrath, 1993; Taylor, Finnie, & Hoy, 1997; Tolcott, Marvin, & Bresnick, 1989; Wickens & Carswell, 1997; Wickens & Holland, 2000; Woods, Johannesen, Cook, & Sarter, 1994). One bias that has particular relevance to the present line of research, the anchoring heuristic, has been studied in several military decision-making domains (e.g. Cohen, Freeman, & Thompson, 1997; Taylor, Finnie, & Hoy, 1997; Tolcott, Marvin, & Bresnick, 1989). The anchoring heuristic is evident when someone acquires only that information which confirms an initial hypothesis, and ignores information which may prove contradictory to that hypothesis (Wickens & Holland, 2000). This selective information-seeking strategy can adversely affect the accuracy and completeness of information.

Another relevant study which used a visual display to present some information in a dynamic battle scenario was conducted by Perrin, Barnett, & Walrath (1993). They presented Naval tactical officers with a dynamic, realistic task simulation (which involved monitoring enemy activity and identifying enemy aircraft). Officers were presented with a combination of visual (2-D radar display) and audio information, which provided near-continuous information updates, and were instructed to create a hypothesis about enemy activity. Afterwards, officers explained their chosen hypothesis by recalling and emphasizing information that supported it better than contradictory evidence, which indicated that they too had been affected by the anchoring heuristic.

In conjunction with the anchoring heuristic, research has shown that people who are seeking information terminate their searches when their confidence level becomes high enough to meet some internal decision-making criteria (Cooper & Sniezek, 1998; Sniezek & Henry, 1989). Since the main effect of the anchoring heuristic is to obtain only that information which appears to support the initial hypothesis completely, the observer's initial hypothesis remains unchallenged and the observer is then able to terminate the search and make a decision with a high level of confidence.

Cohen et al (1997) conducted a paper-based study which demonstrated that officers are not always able to ascertain the completeness of the information upon which they must base decisions. In this study, Army officers were to make sequential judgments based on written information updates about an evolving battlefield scenario. The results indicated that these officers made decisions based primarily on information which confirmed their initial hypothesis and chose not to seek further information which might have contradicted a given hypothesis, evidence that they were affected by the anchoring heuristic. Also, the subjects reported high confidence levels when doing so, indicating that they believed the confirmatory information was sufficient or complete enough to make a final decision, adding support to the link between anchoring and overconfidence.

Given that both anchoring and overconfidence appear to be shown by trained military personnel (Cohen et al, 1997; Perrin et al, 1993), two solutions can be advocated. One approach is to train commanders in metacognitive skills, providing them with the skills necessary to assess their own knowledge and understanding their biases. For example, knowing that people tend to show overconfidence in situation assessment may allow the commander to better "calibrate" confidence to actual quality and completeness of information. Also, teaching commanders about the pitfalls of anchoring to an initial hypothesis to the exclusion of potentially contradictory information may prompt them to consider more in-depth information searches. Cohen et al (1997) demonstrated the success of such training in addressing the anchoring heuristic; officers who were briefed in advance on what cognitive biases were and how they might affect performance showed better information search strategies than officers not given similar metacognitive training.

An alternative approach is to use computer-generated graphic displays to help to integrate and format information in a way that can mitigate such biases, by providing information in a visual, easily understood, and easy to access format (Kleinmuntz & Schkade, 1993). Yet it is also possible that such displays, if their parameters are not carefully chosen, can amplify preexisting biases such as anchoring (Wickens, 1993). To illustrate this point by calling on the four potential causes of cognitive tunneling described above, an observer provided with an interactive display may tend to anchor to the initial information presented:

a) as it acquires an assumed salience of primacy,
b) in order to conserve energy in accessing further information if it is not readily available,
c) by encoding only that information which was the object of focused attention, or
d) by failing to integrate information from other views available in the display.

In other words, an observer may create an initial hypothesis using the initial information that is available (eg. in the forward field of view, prior to interacting with the display, as in Thomas et al, 1999). The observer may feel confident that enough information (or only the important information) has been provided in the initial view to support the initial hypothesis, and may terminate the search for additional information in the periphery, as illustrated by the Immersed participants in Thomas et al, 1999.

1.4. Change Detection

The previous section has discussed anchoring as a cognitive factor that accounts for people's difficulty in changing their beliefs when encountering new information. Another source of difficulty in belief updating is simply that people may not notice changes to the information at all, as was observed to some extent in both conditions (and particularly in the Immersed condition) of Thomas, Wickens, & Merlo (1999). A recent theme in perceptual research has been a focus on the factors that make visual changes in scenes easier or more difficult to notice. We discuss this literature in the current section and its relevance to situation updating in the dynamic battlefield context.

In a battle context, information about enemy units may be changed during updates and it is vital that the commander recognize that changes have occurred in order to accurately update his store of relevant information, as we have noted already. In Thomas et al (1999), verbal reports of change detections differed significantly as a function of view condition, and the change detection performance overall was very low (only 16% of changes were detected). The Tethered condition subjects reported 13 of 45 changes, while only one change (out of 45) was reported by any Immersed participants. The low overall performance can be at least partially attributed to the voluntary verbal nature of change detection reports. In general, the participants did not provide much verbal information despite the emphasis placed on this task in the instructions. It is possible that the participants were attending too much to the computer-based questions and forgetting or ignoring the task of providing verbal reports. It is also possible that the loss of visual momentum across the presentation of successive scenes, due to the abrupt change in position of the viewpoint, contributed to the loss of information about objects within the environment (Woods, 1984), and thus some changes would go undetected. However, despite the low response rate, there was still a significant difference between the performances as a function of viewing condition, supporting the hypothesis that the Immersed condition induced cognitive tunneling, making the participants unaware of changing information in the periphery (Thomas et al, 1999). But this may also be related to the problem of loss of visual momentum, since the Immersed 3-D view's egocentric viewpoint changes more drastically between scenes (and shows less overlap with the previous scene) than the Tethered display's exocentric viewpoint. The use of the wedge in the 2-D inset map of the Immersed condition was intended to improve overall visual momentum across scenes by indicating where the observer was located within the larger environment; however since changes were observed in the 3-D view, participants were still subject to some loss of visual momentum within that view.

As a rule humans are excellent change detectors by necessity. However, it has also been found that detecting changes, specifically in visual displays, can be difficult if these changes occur at a time when the scene is not in view, either during a saccade or a momentary blank screen (Henderson & Hollingworth, 1999; Levin & Simons, 1997; Pashler, 1988; Pringle, Kramer, & Irwin, 2000; Rensink, O'Regan, & Clark, 1997). Several factors have been found to influence the ability to detect changes within a scene; location of the change within the field of view, attendance to the object before the change, and interstimulus interval.

Levin and Simons conducted several studies evaluating change detection in on-going scenarios using short films (1997). In the first study, participants were specifically instructed to pay close attention to the film, and changes could occur to either peripheral objects (such as a clock on the wall) or to objects of central importance (the actors' clothes or the actors themselves). Results showed that even when subjects were told specifically to look for changes, only an average of 2 out of 9 changes (all of which were centrally located changes) were detected. A second study using short films showed that even though participants could describe rich detail about the filmed scene, only a third of participants noticed when the main actor was replaced by a different person (Levin & Simons, 1997). Levin and Simons highlight the established role of attention in change detection (Rensink, O'Regan, & Clark, 1997), which suggests that changes to an object that is not attended (such as a peripheral object) will go unnoticed. Additionally, in agreement with Pashler (1988) and Henderson & Hollingworth (1999), they conclude that information about objects in a scene are not necessarily encoded sufficiently to be tracked over time or to be compared across successive views.

Pashler's research suggested that the duration of interstimulus intervals (ISIs), or blank screens inserted between the original scene and the changed scene, can affect the observer's accuracy in detecting change since the ISIs disrupt the encoding process (Pashler, 1988). This provides evidence that visual short-term memory plays a significant role in change detection ability.

It should be noted that in Thomas et al (1999) as well as the current study, there is a slight interstimulus interval (ISI) between every successive scene, which may have partially contributed to the overall low performance even in the exocentric Tethered display. This ISI was not manipulated as a variable in either Thomas et al or the current study, and is merely a result of the time needed to generate each new scene; it is equal in duration across all scenes, thus any effect it might have on overall performance can be ignored. However, the fact that the Immersed display may present changes out of the initial FFOV can account for the added difficulty in change detection.

In summary, even observers who have been specifically instructed to attend to objects in the environment, who are aware that changes will occur, still show change blindness. Attention, central location of the object, and ISI duration all appear to contribute to an observer's ability to detect changes to objects in a visual display. With regard to the current study, we then expect to see working memory play a primary role in change detection performance (although this does not negate the potential effects of either salience or information access).

1.5. Experimental Questions and Hypotheses

Battlefield visualization requires awareness of own troops and enemy locations in environment (global SA), requires awareness of changing information, and requires orientation skills and interpretation of terrain information (navigation-related tasks). We intend to investigate which type(s) of displays best support these tasks. Also, we evaluate the benefits of applying a "fix" to an existing immersive display in hopes that it will mitigate the display-induced cognitive tunneling observed by Thomas et al (1999). By expanding the experimental paradigm to include more emphasis on change detection, we hope to determine what effects the display-induced cognitive tunneling may have on the ability of an observer to detect changes to objects in the environment. In addition to the greater focus on change detection, participants in this experiment are able to select paths through the environment, which we hope will illustrate the effects that frames of reference have on the ability to accurately interpret terrain information.

In designing the current experiment, we specifically created scenarios which would isolate the effects of each of the hypothesized potential causes of cognitive tunneling (salience, information access failure, or memory failure) as described above. The Tethered and Immersed displays from Thomas et al (1999) were retained with minor modifications (e.g. color changes, icon changes). However, to examine the influence of Salience problems and Information Access failure, we created a third display condition which was visually identical to the existing Immersed display, but with a modification to the interactive panning capability. In the standard Immersed condition (identical to that originally used in Thomas et al, 1999), hereafter referred to as "Self-Panning Immersed," participants could manually control the direction of the viewpoint by using the mouse buttons. In the modified Immersed condition, referred to as "Auto-Panning Immersed," the viewpoint began at the same initial forward field of view (FFOV), but after a short period of time (5 seconds) proceeded to automatically pan through the environment at a rate of 45° per second, stopping every 90° for 5 seconds in the quadrants shown in Figure I2, and completing the cycle at the initial FFOV starting point. The entire automatic panning cycle thus took 28 seconds to return to the initial FFOV, and a minimum of 23 seconds to display the entire 360° (although the last 90° would only just be fully visible at the start of the 23rd second). Providing this automatic panning function was intended to help evaluate information access cost as the cause of performance degradation when using the Immersed display by superceding the need for response inputs by the observer (resulting in no information access cost) in this particular condition.

To determine which of the four causes (salience, information access, working memory, and integration) affects performance, we compare performance in both Immersed conditions to each other and to the Tethered condition. If salience was the main cause of the cognitive tunneling effect in the Immersed display observed in Thomas et al (1999), we expect that both Immersed groups in the present study will be equally affected by the salience of initial FFOV information. The results should show the following pattern (illustrated in Figure I3): on tasks (such as change detection or counting visible enemy units) where all of the relevant information is located in the initial FFOV of the Immersed display, performance between Tethered and Immersed groups should be equivalent; however, both Immersed groups' performance on those tasks requiring information from outside of the initial FFOV will decrease significantly compared to the Tethered condition's performance. If there is no difference in performance between the Tethered and Immersed groups on these tasks, then salience was likely not the primary cause of the effect observed in Thomas et al (1999).

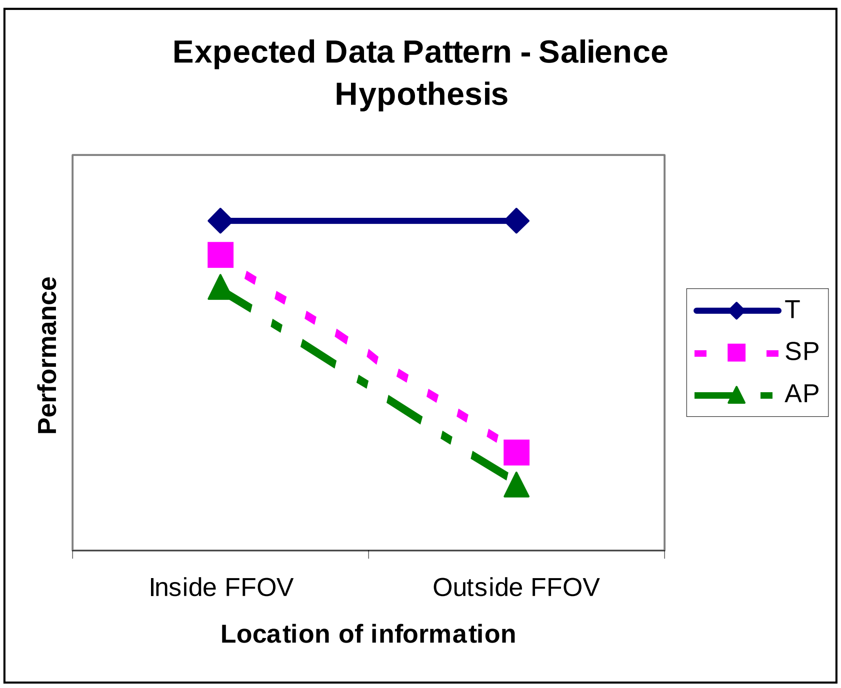


Figure I3. Pattern of data predicted by the Salience hypothesis. The T condition marks highest possible performance, while the two Immersed conditions, SP and AP, show a decline in performance on questions requiring information from outside the FFOV.

If information access cost was the primary cause, then the Auto-Pan Immersed participants, who are presented with peripheral information with no IAC, should perform better on tasks requiring peripheral information than the Self-Pan Immersed participants, who must put forth voluntary panning effort to obtain information outside the initial FFOV. The results would thus show the following pattern, illustrated in Figure I4: performance between the two Immersed groups will be equivalent except for tasks requiring information located outside the initial FFOV, in which case the Auto-Pan Immersed condition will perform significantly better than the Self-Pan Immersed condition.

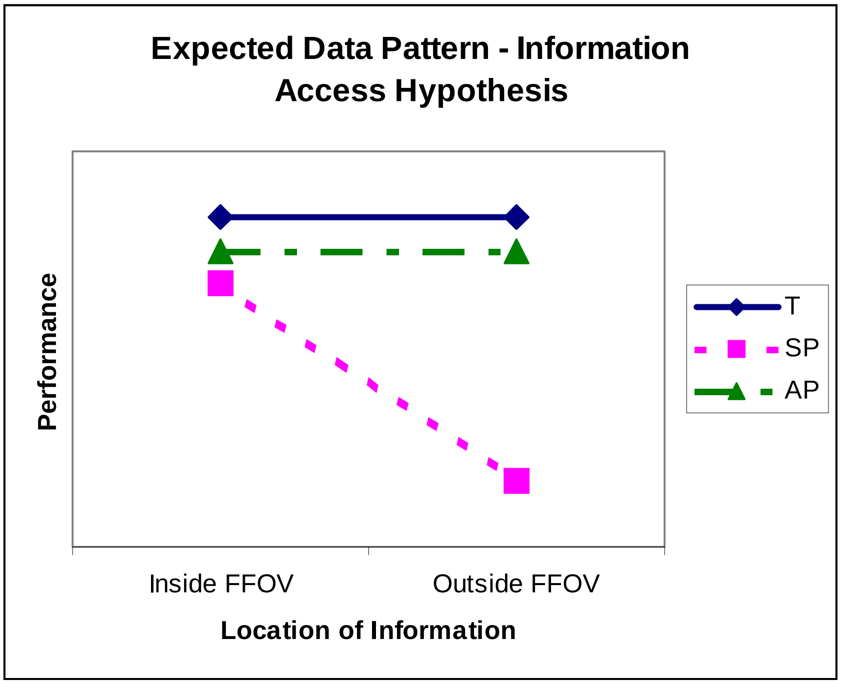


Figure I4. Pattern of data predicted by the Information Access failure hypothesis. The T condition shows highest possible performance. The SP condition shows a marked decline in performance on those questions requiring non-FFOV information, while the AP condition's performance does not change.

In evaluating the role of Working Memory failure, we will compare performance on change detection within the display conditions as well as between them. If memory failure is responsible for the Immersed group's performance decrement in change detection which was observed in Thomas et al (1999), then we expect to see that the detection of changes for each scene in the present study will drop as the number of changes per scene increases. Additionally, it is hypothesized that this effect will be stronger for both Immersed conditions, which will perform less well overall on change detection because of the additional memory workload in retaining information from scene to scene, as well as retaining information about objects located outside the initial FFOV. Finally, research on the effect of object location within a display suggests that, for the Tethered view, peripheral changes (i.e. non-FFOV changes, which are located in the periphery of the Tethered display) will not be detected as well as centrally located (FFOV) changes. Refer to Figure I2 for an illustration of how FFOV and non-FFOV information in the Immersed display maps to centrally-located and peripherally-located information in the Tethered display, respectively. The expected pattern of results, if Working Memory is the primary cause, is illustrated in Figure I5.

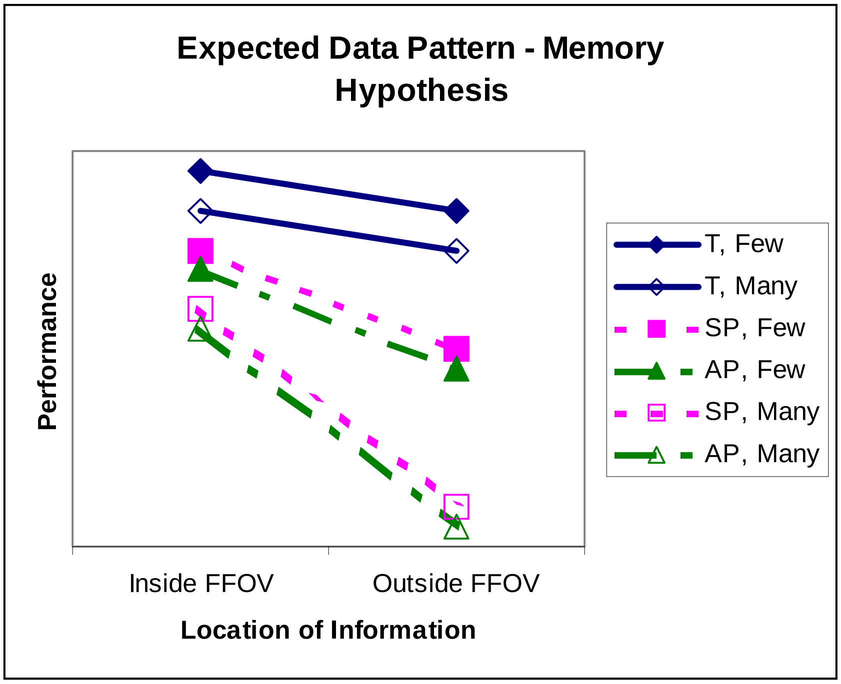


Figure I5. Pattern of data predicted by the Working Memory failure hypothesis. The T condition shows a slight drop in performance from inside to outside FFOV information (which translates to centrally-located vs. peripheral information in the Tethered display), as well as a drop in performance for few changes compared to many changes. The SP and AP conditions show the same trends, but to a greater extent.

These predicted patterns of results can exist in various magnitudes. However, if the results provide no evidence of interactions such as those described above, it is likely that any performance difference between the Tethered and Immersed conditions can be attributed to the problems of integration between the two views of the Immersed display suite as suggested in Thomas et al (1999). Thus we expect that on tasks which require the integration of information that is **only** available in the 2-D inset map with that in the 3-D view, performance will be significantly worse for both Immersed displays than on those tasks where all information is visible in the 3-D view, regardless of the location of that information with respect to the initial FFOV. The data should then produce a pattern such as that illustrated in Figure I6, which indicates this drop in performance for both Immersed conditions, dependent only on the presence of inset-only information, and compared to the perfect results of the Tethered condition (since no integration of information is required).

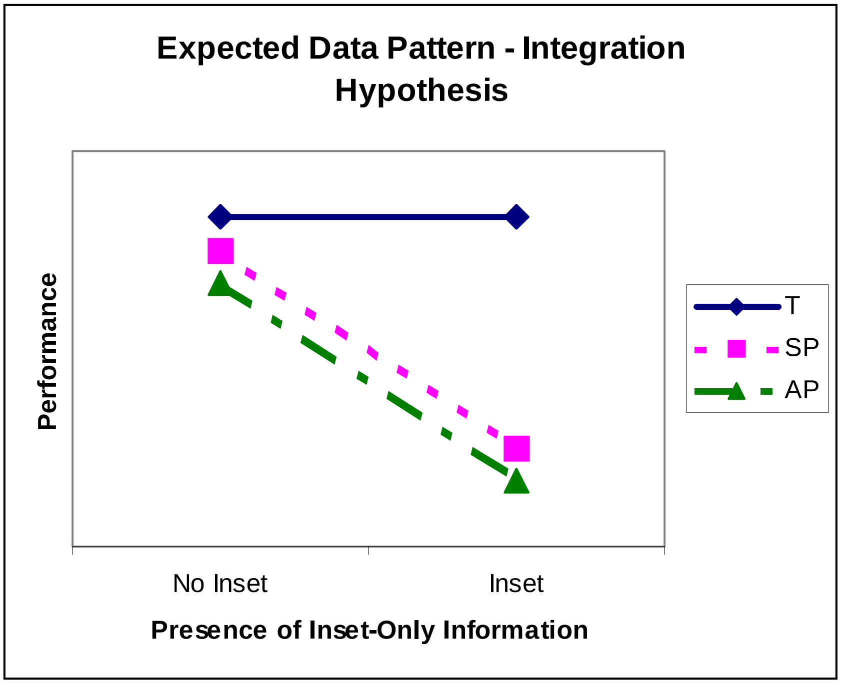


Figure I6. Pattern of data predicted by the Failure of Integration hypothesis. The performance pattern is similar to that shown in Figure I3, except that the cause of the performance drop in the SP and AP conditions is due to the presence of Inset-only information as opposed to non-FFOV information.

In the current study, we attempted to increase the response frequency of change detections (as compared to the relatively low response rate observed in Thomas et al, 1999) by having participants enter detected changes on a menu that is presented at the same time as the computer-based question (at the start of each scene). We predict that the primacy of the change detection menu, as well as the lowered cost of responding, will emphasize this task and produce higher overall responses of detected changes. Also, the focus of the current study was also adjusted to give more emphasis to the task of change detection than was given in Thomas et al (1999).

1.6. Current Experiment

The primary goal of our current study is to investigate the causes of cognitive tunneling observed in the Immersed display of the preceding study (Thomas, Wickens, & Merlo, 1999) by having participants provide counts of visible enemy units as well as detect changes to enemy units in the environment. A secondary focus is on examining the role of viewpoint frame of reference in interpreting terrain information and how the interpretation affects the choice of course of action. Lastly, we expect to replicate and expand on the findings concerning spatial judgments that were observed in Thomas et al (1999).

Participants were assigned to one of three display conditions, which were chosen because they were hypothesized (based on previous research) to best support the majority of the tasks. The first condition (Tethered) was a 3-D exocentric "Tethered" view, as shown in cell B of

Figure I1 and mapped schematically in Figure I2. This frame of reference afforded a view of the area ahead, but also to the sides and behind the observer's location in the environment. The other two conditions (Auto-Pan Immersed and Self-Pan Immersed) employed the same display format – a suite consisting of a 3-D egocentric "Immersed" view (Fig. 1, cell A, also mapped schematically in Figure I2) with a small 2-D plan-view contour map (Fig. 1, cell E) inset in the top center of the larger immersed view. The Immersed view could only show a 90° horizontal range at any one time, while the 2-D map showed the entire area of interest (albeit with degraded information). Neither view in the Immersed display suite contained all of the information necessary to respond correctly: participants sometimes had to integrate information between the two views in order to answer the questions correctly. In order for participants in these two Immersed conditions to observe the entire environment in the 3-D view, two different strategies were employed. In the Auto-Pan Immersed condition, participants passively viewed the surrounding environment in the 3-D view as the viewpoint swept through all 360°, pausing at each 90° for 5 seconds, until returning to the original view. In the Self-Pan Immersed condition, participants were allowed to freely pan the environment themselves using the mouse.

Participants were presented with 50 consecutive scenes of a computer-generated terrain populated by enemy units, which could appear, disappear, change status, or change location between successive scenes. Each successive scene showed the participants' position (as a tank in the Tethered display or 2-D circle in both Immersed displays) at approximately 1.5 to 2 km from the position in the previous scene. This was intended to improve visual momentum by increasing the amount of previously viewed terrain and enemy information in each successive scene (as compared to Thomas et al, 1999).

The participants were asked to detect and report changes to enemy units by selecting options on a computer-based menu. In addition, they were to respond to one or two computer-based questions per scene. The questions required them to make judgments about distances to, direction of, and count of enemy units in the environment. For each question, participants also provided a rating of their confidence in their selected answer. At two different points in the experiment, the participants were asked to choose a path through the environment based on specified criteria. In performing the tasks, participants were instructed to take as much time as necessary, and specifically in the Auto-Pan condition, participants were told to allow the auto-panning feature to complete its cycle before responding to the computer-based questions. These instructions were intended to eliminate any perceived time pressure on the participants and also to maximize the usefulness of the auto-pan feature. At the end of the experiment, they were asked to fill out a questionnaire regarding the usefulness of the display they viewed.

2. METHODS

2.1. Participants

24 students (13 female, 11 male, average age 22.9) from a Midwestern university participated in this experiment and received $6/hour compensation. Each of the participants were quasi-randomly assigned to the three display conditions. One-third were randomly assigned to the tethered display condition, while the remaining two thirds were assigned to either the auto-pan immersed display condition and the self-pan immersed display condition after completing a brief review of contour map information. Participants in these latter two conditions rated their level of familiarity with contour maps after completing the review; expertise levels between the two Immersed conditions were controlled such that both groups had an equal number of participants reporting high, medium, or low familiarity. All but two participants in each Immersed group reported medium familiarity; of those four participants two selected high and two selected low familiarity, and one of each was placed in each Immersed group.

2.2. Apparatus

The experiment was displayed on a 21” SGI monitor and run using BattleView software on a Silicon Graphics Octane workstation. The terrain information was produced from geological surveys of the National Training Center in Ft. Irwin, California. A terrain image of the area was obtained from a true-color satellite photo of the area. Participants were seated approximately 1.5 to 2 feet (or similar comfortable viewing distance) from the screen.

Participants in all three conditions used the mouse to respond to changes they detected in the environment by selecting the object’s identifying letter and type of change from a menu on the right side of the map display. They also used the mouse to select answers and confidence ratings for the computer-based questions, presented below the menu to the right of the map display. Participants in the self-pan immersed condition were also able to manipulate the display viewpoint by “panning” to the left or right, a function which is described in more detail below.

2.3. Stimuli

The three display view conditions evaluated in this study offer three distinct viewpoints that contain different frame of reference features. All three displays showed a relatively flat-bottomed valley surrounded by mountainous terrain. Figure M1 provides an overview of the entire battle area, looking to the west.

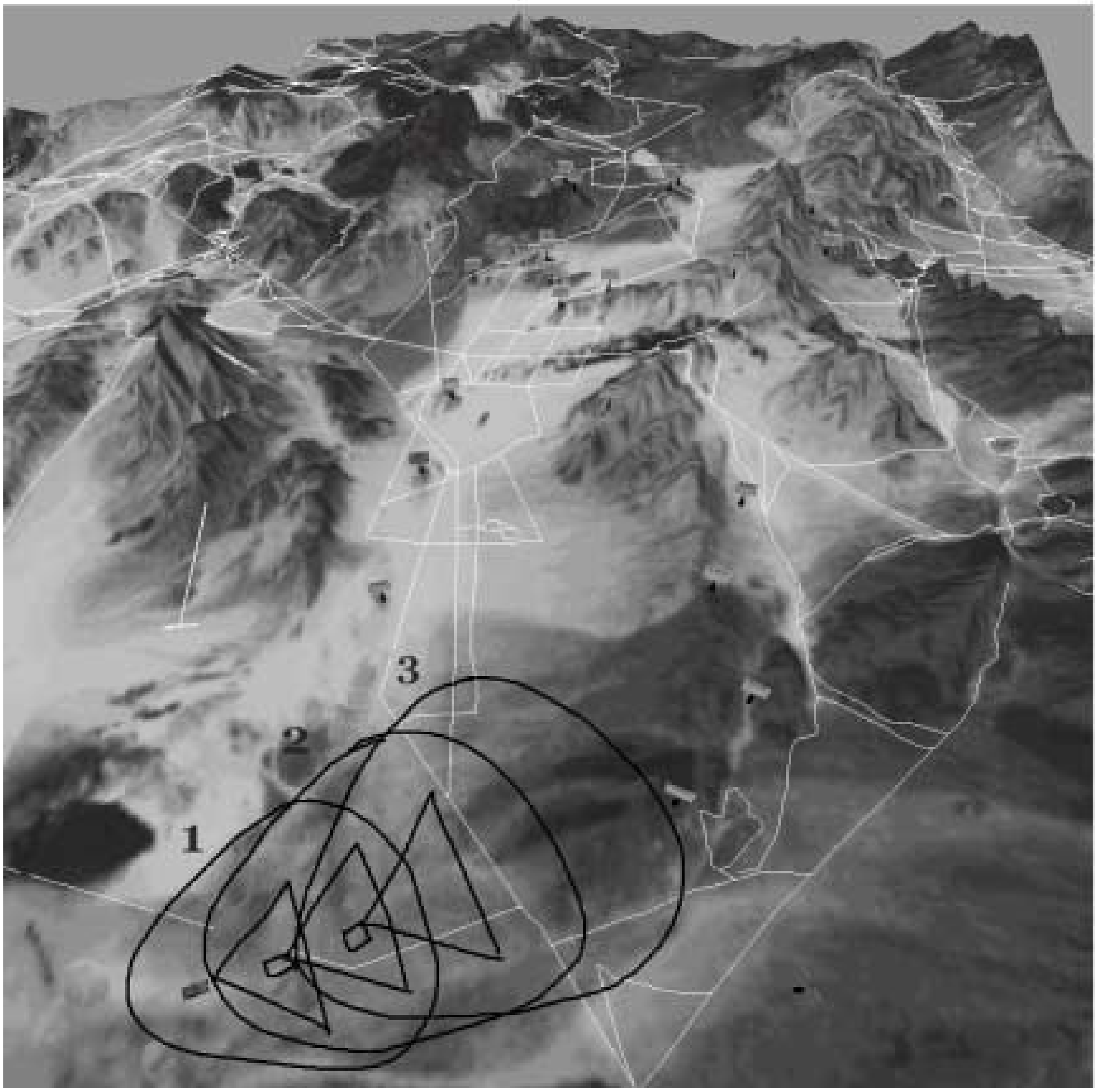


Figure M1. View of the entire battlefield with the "footprints" of the first three scenes, illustrating the overlap in both the Tethered (oval footprint) and Immersed (triangular footprint) displays.

The path through the terrain was depicted in a series of 50 successive scenes, represented by the three sets of overlapping "footprints" on the terrain in Figure M1. Each set of footprints illustrates the overlap between display conditions as well as the overlap between successive scenes for each display condition. The forward field of view in each display, however, was not limited by the enclosed part of the footprint located directly in front of the tank's position; within the display the horizon was infinite, limited only by terrain features (such as mountain ranges). Each scene change represented an advance of about 1.5-2 km along the path of travel, such that each scene had an overlap of about 80% of terrain and enemy information from the previously viewed scene. Since the path curved from north to west to northwest over the course of the 50 scenes, the degree of overlap between successive scenes varied but, generally speaking, a high degree of visual continuity was maintained throughout the scene presentation.

2.3.1. <u>Tethered condition</u>. The Tethered display condition consisted of a 3-D exocentric view, where the viewpoint was always located approximately 3000 meters above the ground and 1200-1500 meters behind the ego reference point, a realistic tank icon. Figure M2 depicts a sample scene presented to the participants in the Tethered condition.

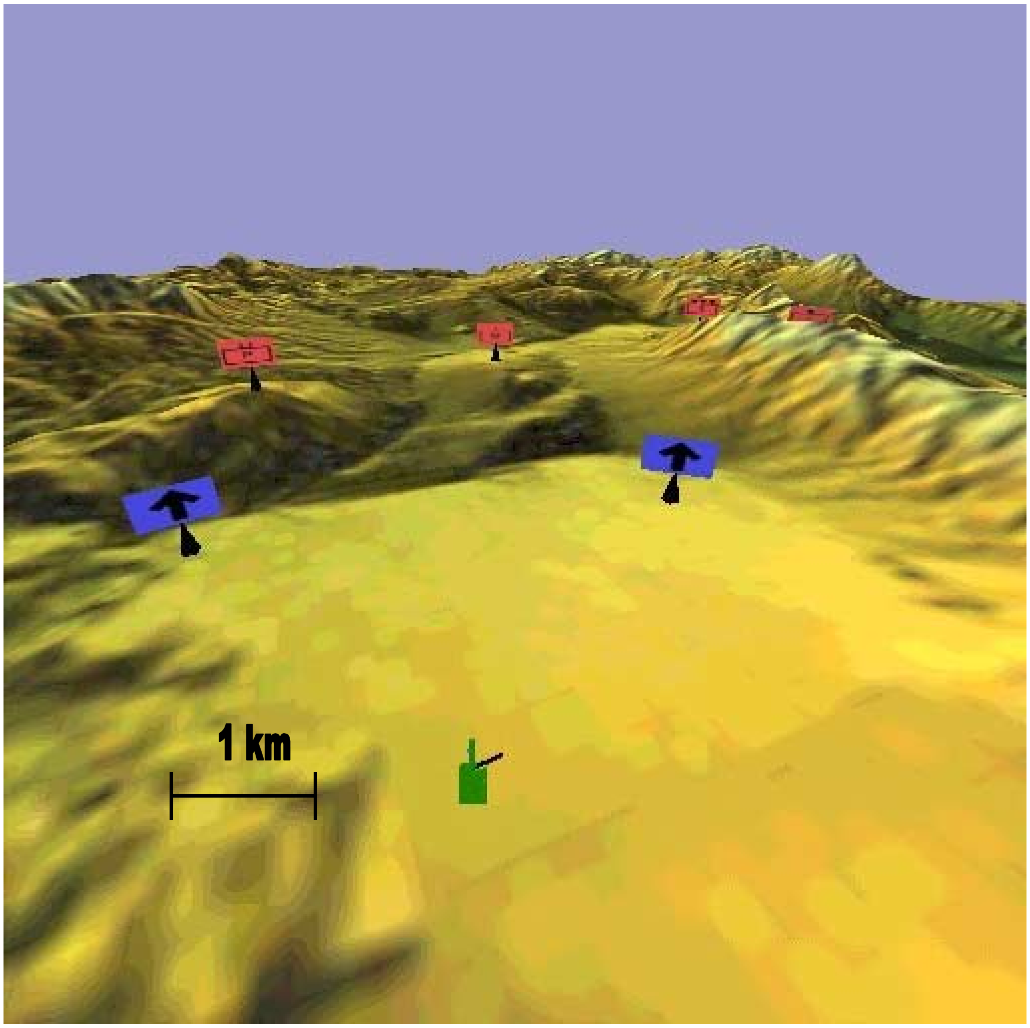


Figure M2. Exocentric ("tethered") 3D display, with observer's location represented as the tank and enemy units as signposts. The two arrows denote possible path headings for path selection questions.

The viewpoint was always oriented along the movement of the unit into battle, such that the tank icon was always facing towards the top of the display, and the areas behind, to the sides, and in front of the tank could be seen. This positioning of the viewpoint above and behind the tank icon produced the effect that the tank was always visible at approximately the same location on the screen (centered in the bottom third of the screen) for each successive scene. This "footprint" area seen in each tethered display scene contained all of the information necessary to respond correctly to the question(s) for that scene, but no more information than could be seen in the Immersed displays (when panned) for the corresponding scene.

The participant could not interact with the Tethered display, but instead observed the scene passively. A marked 1 km line scale located directly to the left of the tank icon in each scene was added to assist in distance calibration. A small black line positioned directly above the tank icon acted as a compass needle, pointing to due North in every scene, and direction of heading could be determining by gauging the angle between the black compass line and the green gun barrel of the tank icon.

2.3.2. Immersed conditions. The Immersed display conditions presented two viewpoints simultaneously. Figure M3 shows a sample scene presented to participants in both Immersed conditions (the AP Immersed and SP Immersed initial views are identical).

The main part of the immersed display suite was a 3-D egocentric view which depicted approximately the same terrain as the tethered condition, but from the perspective that the commander would have at eye level (2 meters above the ground) from his/her location. The default view at the start of every scene showed the terrain directly ahead according to the battalion's trajectory (i.e. oriented along the same axis as the tethered view for that same scene). This view encompassed a 90º geometric field of view at any one time. Given this limited field of view, participants in the two Immersed conditions were not initially presented with the same amount of information available to participants in the Tethered condition. Thus, in order for SP and AP Immersed participants to acquire all of the information necessary to respond correctly to the computer-based questions, additional sources of information were required. One additional source was a small 2-D contour map located in the top center of the 3-D view, which was common to both SP and AP displays. The other source was the capability to pan the entire 360º of the environment within the 3-D view; the manner of panning differed between SP and AP conditions.

Embedded in the 3-D immersed view of both the AP and SP Immersed display suites, a small (2.5 x 3 inch) 2-D exocentric contour map located at the top center of the screen displayed the entire area of interest. The inset map was positioned in such a way that it did not obscure any relevant information from the immersed view (i.e. only part of the sky was covered by the inset map).

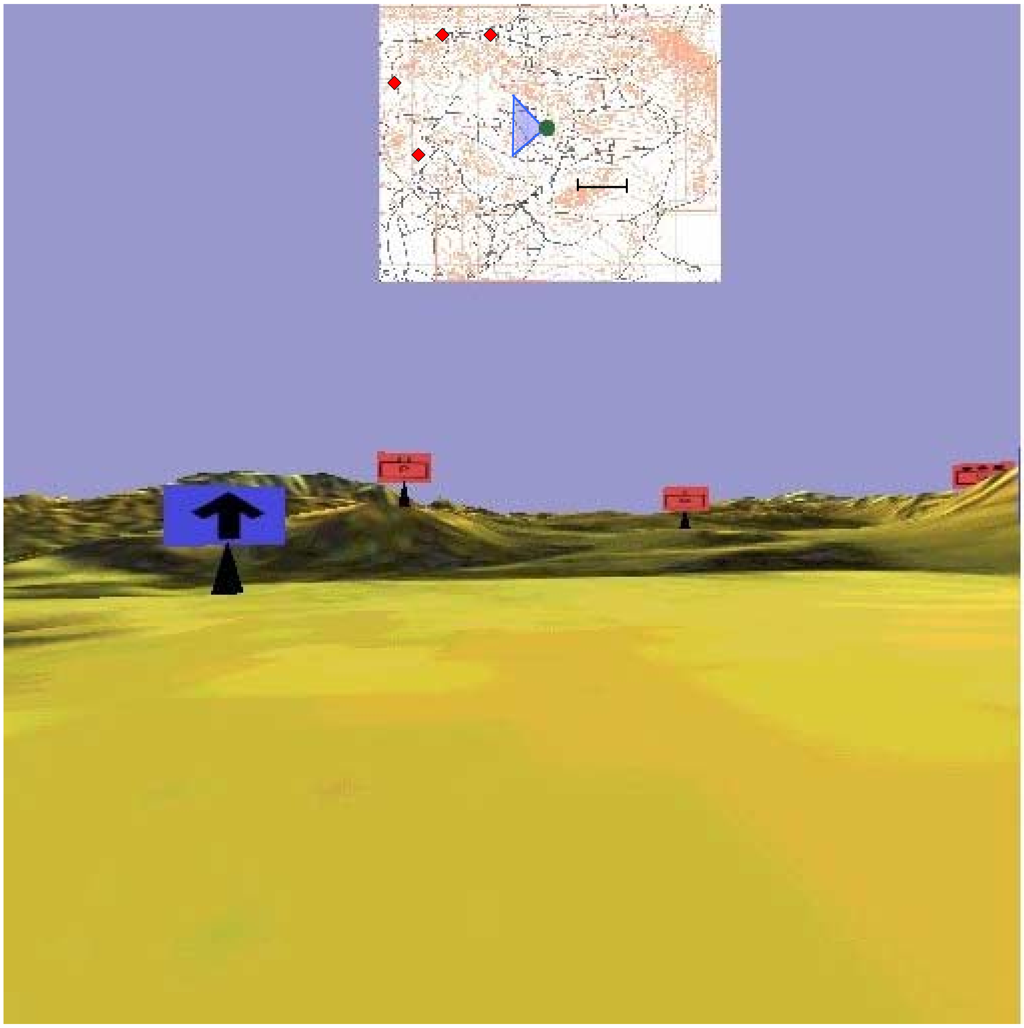


Figure M3. Immersed 3D display. Enemy units are depicted as signposts, and one arrow is visible, denoting a possible path choice for path selection questions. The small map at the top is a plan view, with the observer's location and forward view depicted by the green circle and connected blue wedge, respectively, and confirmed enemy units are depicted as small red diamonds.

Participants in these conditions could track their battalion's progress in the 2-D inset map and observe the terrain from the tank's perspective in the immersed view map. The 2-D inset map consisted of a white background with light brown contour lines and black lines which represented the roads in the environment. In addition, a grid of 10km by 10km squares was superimposed on the 2-D inset map to aid with distance calibration. One line section of the grid was darkened to emphasize that each grid section was 10 km in length. The commander's current location on the 2-D inset map was depicted by a small green circle. The area currently visible in the 3-D immersed view was represented on the 2-D inset map by a blue "wedge," (Aretz, 1991) which acted like a spotlight to show what portion of the inset map was seen in the 3-D view. The wedge opened up in the direction the commander was facing and illustrated the extent of the view seen in the 3-D immersed view. As participants panned the environment, the wedge rotated correspondingly to highlight the new regions currently being viewed. The 2-D inset map was north-up; by noting their position on the map and the direction of the wedge, participants could obtain relative heading information. Thus the 2-D map provided distance and direction information (which was not available in the 3-D view), as well as information on confirmed enemy units which may be completely hidden by terrain features in the 3-D view.

The second source of information was the display's capability to show the entire 360º range within the immersed view. In the AP Immersed condition, participants were presented with the initial FFOV for 5 seconds, then passively observed as the screen automatically and continuously panned through the entire 360º range or until the scene's question was answered, pausing every 90º for 5 seconds and finally ending back on the initial FFOV. The panning direction was always to the left in the AP condition. Total time for the entire automatic panning sequence was 28 seconds (5 seconds for the initial view, 8 seconds total to continuously sweep through all 360º, and 15 seconds total of pauses at each 90º). The 5-second pauses were included in order for the participants to have sufficient time to view the information presented without becoming bored or distracted. Since the geometric field of view was 90º, this meant that every part of the full 360º of the environment was viewed statically for 5 seconds, and for an additional 2 seconds during the panning.

The Self-Pan (SP) Immersed display condition was composed of the same two viewpoints (3-D immersed view and 2-D inset map) as the AP Immersed display and presented the same initial default view, but participants were able to freely rotate the viewpoint by horizontally panning the viewpoint, using the mouse, to cover the entire 360º range. In the SP condition, participants could pan either to the left or right by alternately clicking the left or right mouse buttons. The participants could place the cursor over any part of the display, click the left button, and the view would pan to the left. Similarly, clicking the right mouse button would result in the viewpoint turning to the right. Single clicks of the mouse button resulted in discrete changes to the viewpoint of 10 degrees to each click. Holding the button down resulted in a continuous sweep of the area, including the entire 360º rotation, which would be completed in 8 seconds (i.e. the same rate of panning as in the auto-pan condition). Releasing the button would cause the panning to stop. Tethered and auto-pan immersed participants were not given this voluntary panning option.

For both AP and SP Immersed conditions, panning the environment only presented that information which was visible in the 3-D egocentric view (e.g. unconfirmed enemy units, all enemy units not obscured by terrain features). Neither the 2-D inset map nor the 3-D immersed view alone contained all of the necessary information to answer the questions correctly, but the combined information from both sources was always sufficient. To illustrate, the 2-D inset map may show a confirmed enemy unit that is not visible in the 3-D immersed view because it is blocked from view by a mountain range or is "behind" the current orientation (outside the initial FFOV) and can only be seen after panning. Alternatively, the 3-D immersed view may show several unconfirmed enemy units that don't appear on the 2-D inset map because this map only depicts confirmed intelligence information. For every scene, both views are needed to get the most complete information.

2.3.3. Enemy symbols. In both 3-D perspective views (immersed and tethered), enemy units were represented by red "signposts" marked with standard military symbols for size (e.g.

company, platoon) that were embedded within the terrain such that terrain features could partially or entirely obscure the signpost (source: FM 101-5-1, *Operational Terms and Symbols*). Examples of these symbols are present in Figure M4. All enemy units also contained an identification code (a letter), which was clearly legible and distinguishable from the enemy symbol. Participants were informed that unconfirmed units were marked with dashed lines, while confirmed units were marked with solid lines. Unconfirmed units were considered to be "templated," that is, based on preliminary or unreliable information, and either became confirmed in a subsequent scene or disappeared altogether if the information was assessed by intelligence to be incorrect. Confirmed enemy units were based on reliable information, and could either appear in place of an unconfirmed unit from one scene to the next (e.g., following confirmation from further intelligence) or could appear from nowhere (e.g. certain initial sighting). Enemy (confirmed and unconfirmed) symbol were visible as signposts in the Tethered condition and in the 3-D immersed view of both Immersed condition. However, in the 2-D inset map in the Immersed conditions, only *confirmed* enemy targets were visible and depicted as small red diamonds; no unconfirmed enemy units were shown.

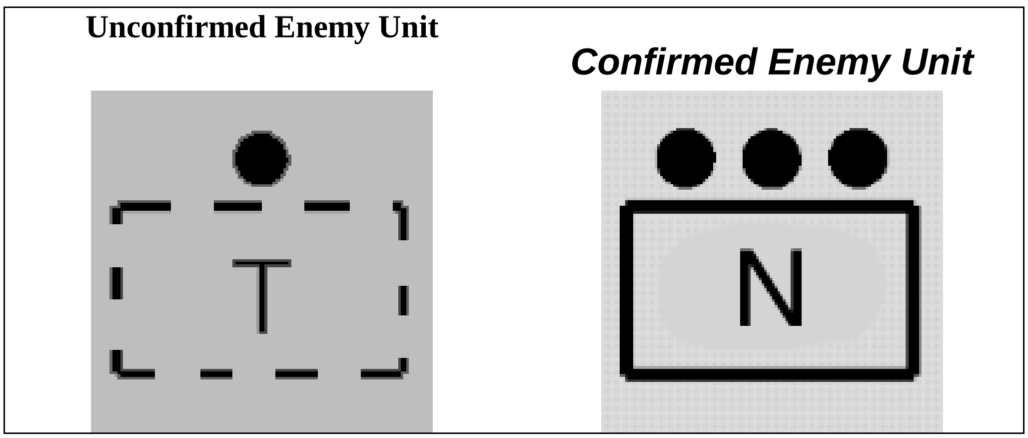


Figure M4. Enemy symbols.

2.4. The Battle Scenario

The first section of the battle scenario was intended to let participants familiarize themselves with the display and the type of information to be encountered. The battalion was initially positioned facing due north, traveled north for the first 10 scenes, and then turned towards the west and continued in that direction until Scene 31. Enemy units began to appear in Scene 2. One or more changes to enemy units (appearances, disappearances, or changes in status or location) occurred in most scenes.

Scene 31 marked the second section of the experiment. Prior to this point in the experiment, participants did not control their heading or progress through the environment. But after Scene 31, as the battalion progressed northward toward a mountain pass, participants were given two opportunities to select the "best" path to a specified location in the environment. At the first choice point (Scene 31), participants were presented with 3 distinct paths marked by arrows through the environment. Before making the final path selection, they were asked computer-based questions which evaluated the relative weights that participants assigned to the relevant factors of enemy threat and terrain composition. In the first question, participants were told to assume that the paths were equal in terms of terrain passability and were asked to choose the path based solely on enemy location. In the second question, participants were told to ignore the enemy locations and choose a path based on terrain composition. The final computer-based question for Scene 31 asked participants to make a final path choice, taking both factors (terrain and enemy location) into consideration. In Scene 31, one path was through more level terrain but was more heavily defended by the enemy, another path consisted of more mountainous terrain but was less threatened by enemy positions, and the third path had little enemy threat and was smooth terrain but led away from the goal. Once this final path was chosen, the corresponding next scene (scene 32) appeared. Depending on which of the three paths were chosen, participants saw a different successive view and different enemy information. In each case, all path options converged to the same location after one scene change (Scene 33). A second choice point with two optional paths denoted by arrows appeared in Scene 39 (without the hypothetical questions preceding it), as shown in Figures M2 and M3.

Throughout the entire battle scenario, enemy units could appear, disappear, change status, or change location across consecutive scenes, and participants were expected to spontaneously report as many changes as they could detect. Unconfirmed enemy positions could appear, disappear or change to confirmed status, but did not change location. Confirmed enemy units could either appear, disappear, or change location, but did not change status, and only one enemy unit changed location one time. Also, changes only occurred between successive scenes, never within a single scene. One or more instances of one or more types of changes could occur between two consecutive scenes. A summary of change types is presented in Table M1.

Table M1. Possible changes to enemy units from scene N to scene N+1. * Only one unit changed location.

	Unconfirmed Enemy	Confirmed Enemy
Appear	Yes	Yes
Disappear	Yes	Yes
Move location	No	Yes*
Change Status	Yes (to Confirmed)	No

2.5. Tasks

Once the participants were assigned to one of three display conditions (Tethered, AP Immersed, or SP Immersed), each group was given instructions specific to that condition. The participants read and signed the consent form, read the instructions, and were given the opportunity to ask questions at any time. Once they had finished reading the instructions, the experimenter went over the main tasks and emphasized the importance of completing the three tasks in order as discussed below. For AP and SP Immersed conditions, the experimenter read a brief overview of general contour map information and each participant was asked to provide a rating of map-reading familiarity.

There were three tasks involved in this experiment; two tasks were performed simultaneously during the scene presentation, and the third was performed after all of the scenes had been observed. The participants were told that, once the scenes began, they should first respond to any new enemy locations and/or changes to the status (e.g. unconfirmed to confirmed) of existing enemy units, relative to the previous scene. A change-detection menu box was always present to the right of the display, and the experimenter illustrated proper use of the menu during the first (trial) scene. Participants responded to detected changes by selecting the letter of the icon from the menu and then selecting one of the four types of changes. Each change had to be fully recorded with a letter and change type before the next change could be recorded. Changes could be recorded at any time during a scene, although once the computer-based questions were completed for that scene, the scene disappeared and the successive scene appeared.

Following the reporting of any changes for each scene, the second task for participants was to respond to computer-based questions and provide confidence ratings, both of which were presented in boxes in a column to the right of the terrain display and did not obscure any part of the display. For each display condition, each scene's question box (or first question box if more than one) was present from the start of the scene. Each scene contained one or two questions. Answer and confidence rating choices were always displayed as buttons within the boxes, which the participant could click on with the mouse. The questions consisted mainly of the navigational task components of distance and direction judgments and a global hazard awareness task requiring tallies of enemy units (for confirmed, unconfirmed, or both). Each question had 3 multiple-choice answers (one of which was correct). Each confidence rating box had 3 confidence levels to choose from ("highly confident," "moderately confident," and "not at all confident").

For both Immersed conditions, some questions did not require any panning at all since all relevant information was included in the initial FFOV (labeled "Forward" type questions). These questions included all of the spatial judgment questions as well as those enemy count questions which required a count of **confirmed** enemy units, all of which were clearly visible within the initial FFOV of the 3-D view as well as on the 2-D map. An example of a Forward question is "How many confirmed enemy units are visible?"

However, the remainder of the enemy count questions required some amount of panning in order to obtain all of the relevant information. These questions were further categorized by the type of information required from the environment. First, "Pan-Required Unconfirmed" questions were those which required the participants to obtain information about **unconfirmed** enemy units, some of which were located outside the initial FFOV. An example of this type of question is "How many unconfirmed enemy units are visible?" Next, "Pan-Required All" questions were those which required the participants to obtain information about **all** (confirmed as well as unconfirmed) enemy units, some of which were located outside the initial FFOV but all were clearly visible in the 3-D view. Finally, "Pan-Required Inset" questions also required the participants to obtain information about **all** enemy units; however in this case, some of the **confirmed** enemy units were not visible in the 3-D view at all (obscured by terrain features) and so participants had to gather information from the inset map and accurately integrate it with the visible 3-D view information in order to respond correctly. Although confirmed enemy unit information was always available in the 2-D view, none of the questions in the other categories **required** this integration. For these last two categories, the questions were phrased similarly, "How many total enemy units are visible?", but differed in the source of information.

Once an answer was selected for each computer-based question, the answer remained highlighted and a confidence rating box appeared below the question box. Participants were to provide a confidence rating to the selected answer from “Very Confident,” “Moderately Confident,” and “Not At All Confident.” If the scene had more than one question, then a second question box replaced the initial question box, otherwise the next scene began after the confidence rating was provided, and the corresponding first question would automatically appear. Participants who did not respond to changes for a scene before responding to all questions in that scene were not able to record any changes for that scene as it was automatically replaced by the successive scene after the last question was answered. Participants in the AP condition were specifically instructed to allow the auto-pan feature to complete its 360º cycle of the environment before responding to the computer-based questions, so that they could obtain all of the necessary information. All participants were told that there was no time limit on any of the tasks.

After all scenes were viewed, the participants’ third and final task was to fill out a questionnaire which asked them to rate the display according to how useful it was in providing information about the environment and to describe any benefits or problems they observed with the display. After the questionnaire was completed, the experimenter thanked the participants, paid them, and debriefed them on the purpose of the experiment.

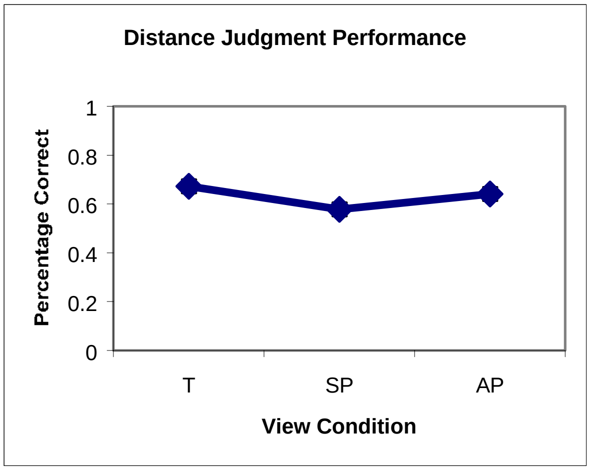
3. RESULTS

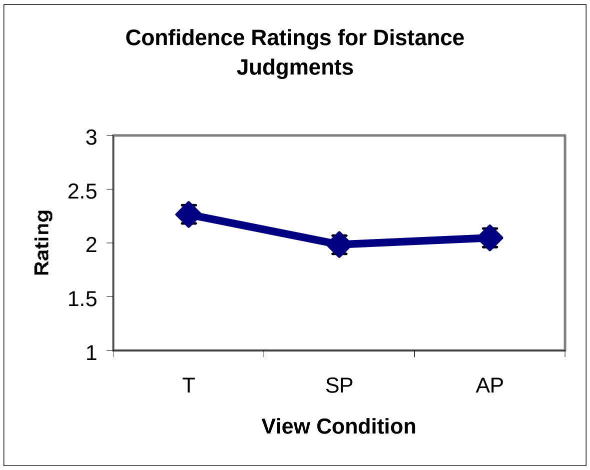
The data were analyzed using the Statistical Analysis Software (SAS) package. There were a total of 51 questions. Four questions which dealt with path selection (and thus had no single “correct” answer) were analyzed separately from the accuracy testing questions and were omitted from performance analyses. An additional question which asked for a subjective appraisal of the terrain, and thus had no “correct” answer, was also eliminated from further analyses. The remaining 46 questions were then filtered according to an overall response criterion; if participants from all three viewing conditions responded correctly at less than chance level, the question was dropped from further analysis. Two questions failed this criterion, resulting in a total of 44 questions on which statistical analyses were performed.

3.1. Spatial Judgments

The 44 questions were categorized into three groups based on the type of judgment required by the question. The category criteria match those used in Thomas, Wickens, & Merlo (1999). The three groups were distance judgments (8 questions), heading (or direction) judgments (21 questions), and judgments requiring a count of visible enemy units (15 questions). Statistical analyses on accuracy of performance, response times, and confidence ratings were conducted on the data for each of the view conditions, Tethered (T), Self-Pan Immersed (SP), and Auto-Pan Immersed (AP).

3.1.1. <u>Distance judgments</u>. The 8 distance judgment questions were analyzed. The data indicated no differences in performance [$F(2,21) = 1.08$, $p<0.36$] or confidence [$F(2,21) = 0.79$, $p<0.47$] by view conditions, as shown in Figures R1a and R1b.





Figures R1a and R1b. Performance and confidence ratings for distance judgment questions by view condition, with standard error bars.

All view conditions produced equivalent performance on distance judgment questions, indicating that none of the displays aided this judgment in an especially effective manner. Response times showed a significant increase across view conditions [$F(2,21) = 4.70$, $p<0.021$], shown in Figure R1c. Although no panning was necessary to answer distance questions correctly, the increase in response times for SP and AP conditions reflects the panning necessary to report changes in the environment, which needed to be completed before the participants could respond to the computer-based questions.

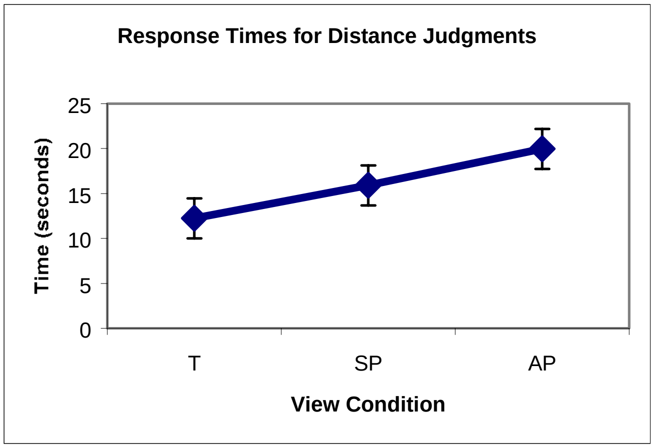


Figure R1c. Response times for distance judgment questions by view condition, with standard error bars.

3.1.2. <u>Heading judgments</u>. On heading judgments, there was a significant effect of view condition on performance [$F(2,21) = 3.54$, $p<0.047$], illustrated in Figure R2a. T participants' performance was significantly better than SP ($t_{14}=2.17$, $p<0.048$) and AP ($t_{14}=2.13$, $p<0.051$), which were not significantly different from each other ($t_{14}=0.20$, $p<0.84$).

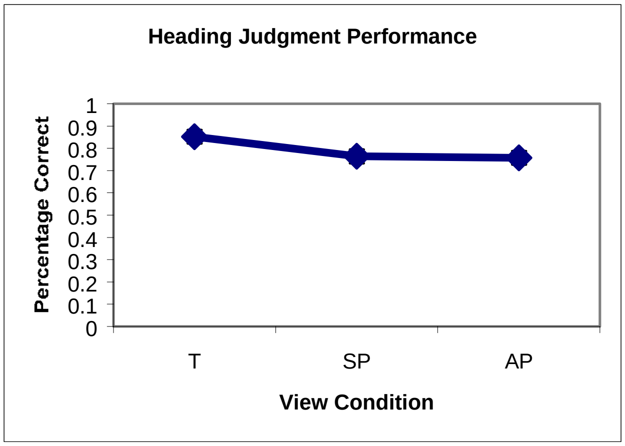
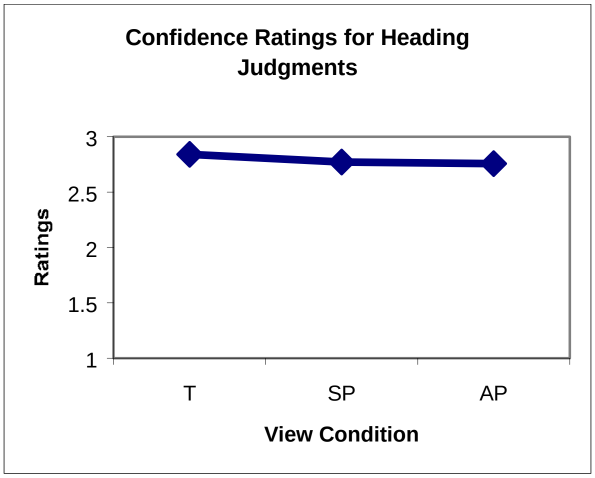
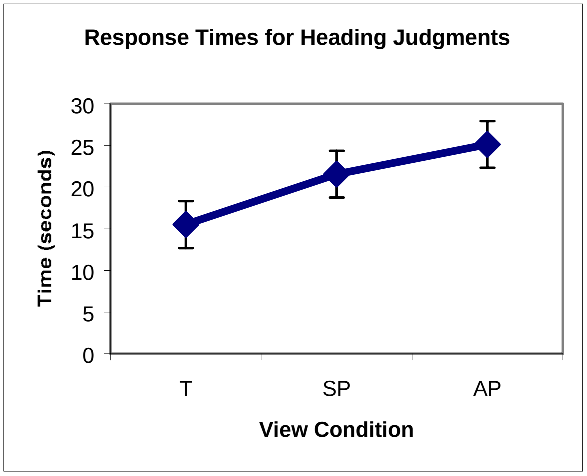


Figure R2a. Performance on heading judgment questions by view condition, with standard error bars.

However, neither the confidence ratings [F(2,21) = 0.48, p<0.62] nor response times [F(2,21) = 2.08, p<0.15] for this task showed significant effects of view condition (Figures R2b and R2c).





Figures R2b and R2c. Confidence ratings and response times for heading judgment questions by view condition, with standard error bars.

3.2. Enemy Count Questions

Data from the 15 enemy count questions were evaluated and categorized by the panning strategies that we expected participants in the Self-Pan Immersed (SP) condition to adopt when responding to the question. Auto-Pan Immersed (AP) participants did not have a self-initiated panning option and thus were limited to passive scanning strategies. Tethered (T) participants were presented with all information in one static scene and did not have a panning option or panning-related strategy. Since T participants were given all necessary information in one view while SP and AP participants had to occasionally rely on the panning function, T performance served as a baseline for comparison. The four panning strategy categories for the SP condition are:

1. "Forward" (3 questions): these questions asked specifically for counts of CONFIRMED enemy units, which could and should have been made based entirely on information within the initial FFOV in the Immersed display. A sample question is "How many confirmed enemy units are visible?". In all instances of this category, all of the confirmed enemy units were located within the initial FFOV of the 3-D view, therefore no integration of the inset map information was necessary even though confirmed enemy unit information is also presented there.

2. "Pan-Required: Unconfirmed enemy units" (3 questions): these questions asked for counts of UNCONFIRMED enemy units (labeled "PR (unconf)"). Participants were to pan the entire environment to gather all information in order to answer these questions correctly, since unconfirmed enemy units were only visible in the 3-D egocentric view, not on the 2-D inset map. A sample question from this group is "How many unconfirmed enemy units are visible?"

3. "Pan-Required: All enemy units" (4 questions): these questions asked for ALL enemy units (confirmed and unconfirmed, labeled "PR (all)"). Since unconfirmed units are included in these questions, participants had to pan the entire environment to gather all relevant information for these questions as well as the Pan-Required questions described above. For these questions, all units were clearly visible in the 3-D view so that no integration of inset-map information was necessary. A sample question from this group is "How many total enemy units are visible?"

4. "Pan-Required: Inset-only information" (5 questions): these questions asked for ALL enemy units, similar to category 3 (see 3 for sample question). However, these questions differ from category 3 by requiring participants to obtain information that was only available on the 2-D inset map as well as information outside the initial FFOV in order to answer the questions correctly. In all instances of this category, one or more of the confirmed enemy units was hidden from view in the 3-D view, but was visible on the 2-D map. Therefore participants had to integrate that information from the 2-D map with the other visible enemy unit information from the 3-D view in order to respond correctly. Although confirmed enemy unit information was always available in the 2-D view, none of the questions in the other categories **required** this integration.

3.2.1. Accuracy. Proportion of correct responses to the enemy count questions within each panning category (and subcategory) were calculated for each participant. A 2-way ANOVA was conducted on these data for panning behavior category by view condition, as seen in Figure R3a. There was a significant main effect of view condition [$F(2,93) = 16.56$, $p<0.01$]. T participants' performance was significantly higher than either SP ($t_{62} = 2.73$, $p<0.01$) or AP ($t_{62} = 5.83$, $p<0.01$), and the SP performance was significantly better than AP ($t_{62} = 2.16$, $p<0.35$).

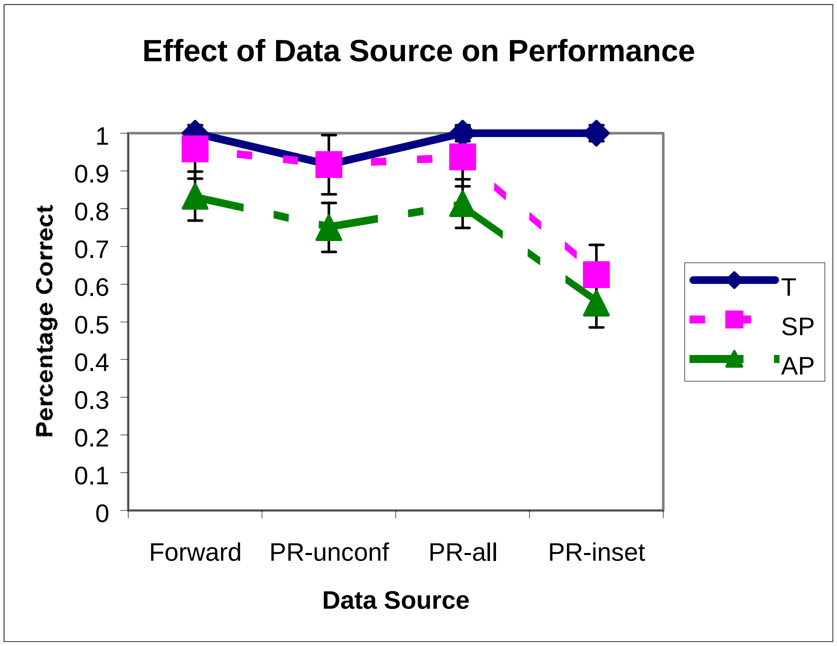


Figure R3a. Performance on count of enemy visible questions for each panning category by view condition, with standard error bars.

There was also a significant main effect of pan strategy [$F(3,92) = 7.42$, $p<0.01$]. Forward questions produced equivalent performance as pan-required questions asking about unconfirmed enemy units ($t_{46} = 1.32$, $p<0.19$) as well as pan-required questions asking about unconfirmed enemy units ($t_{46} = 0.31$, $p<0.76$), which were also equivalent ($t_{46} = 1.13$, $p<0.26$). However, PR-inset questions produced significantly lower performance than Forward ($t_{46} = 3.11$, $p<0.01$), PR-unconf ($t_{46} = 1.98$, $p<0.05$), and PR-all ($t_{46} = 3.03$, $p<0.01$).

The interaction between panning category and view condition was significant [$F(6,89) = 2.35$, $p<0.038$]. Figure R3a reveals that the primary contribution to this interaction is the drop in performance for both Immersed groups on the PR-inset questions, a drop which is not present for the Tethered condition.

3.2.2. <u>Response times by pan strategy</u>. A 2-way ANOVA was performed on the response time data for the count questions, shown in Figure R3b.

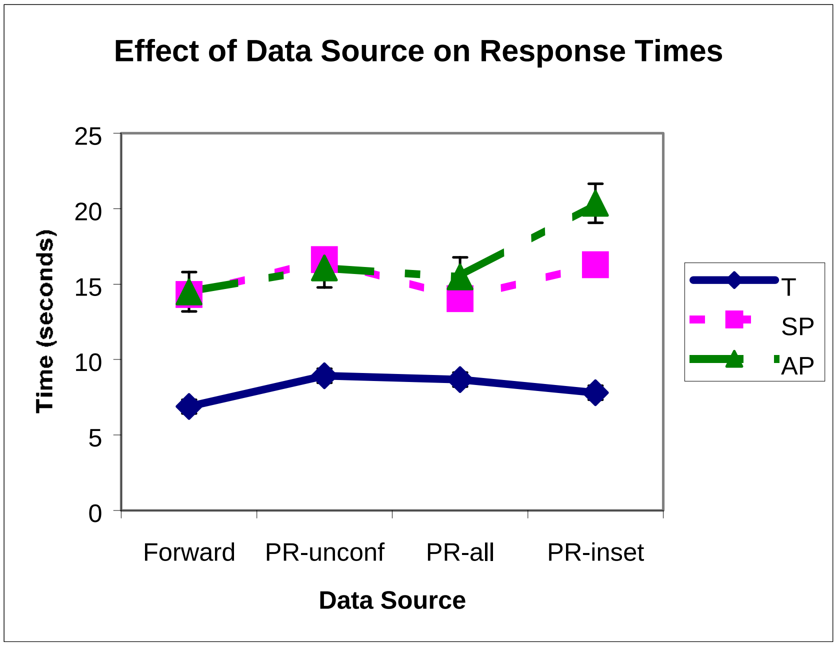


Figure R3b. Response time data for enemy count questions by view condition and pan strategy, with standard error bars.

There was a significant main effect of view condition [$F(2,93) = 15.30$, $p<0.01$], as T participants were significantly faster than either SP ($t_{62} = 5.36$, $p<0.01$) or AP ($t_{62} = 5.50$, $p<0.01$), which were not significantly different from each other ($t_{62} = 0.84$, $p<0.41$).

The main effect of pan strategy was not significant [$F(3,92) = 0.67$, $p<0.57$], indicating that within each of the view conditions, participants spent about the same amount of time answering questions in each category.

The interaction between pan strategy and view condition was not significant [$F(6,89) = 0.35$, $p<0.91$].

3.2.3. <u>Confidence ratings</u>. A 2-way ANOVA was conducted on the confidence rating data within each panning category by display condition, shown in Figure R3c. There was a main effect of both pan strategy [$F(3,92) = 4.11$, $p<0.01$] and view condition [$F(2,93) = 21.86$, $p<0.01$], as well as a significant interaction [$F(6,89) = 2.25$, $p<0.046$].

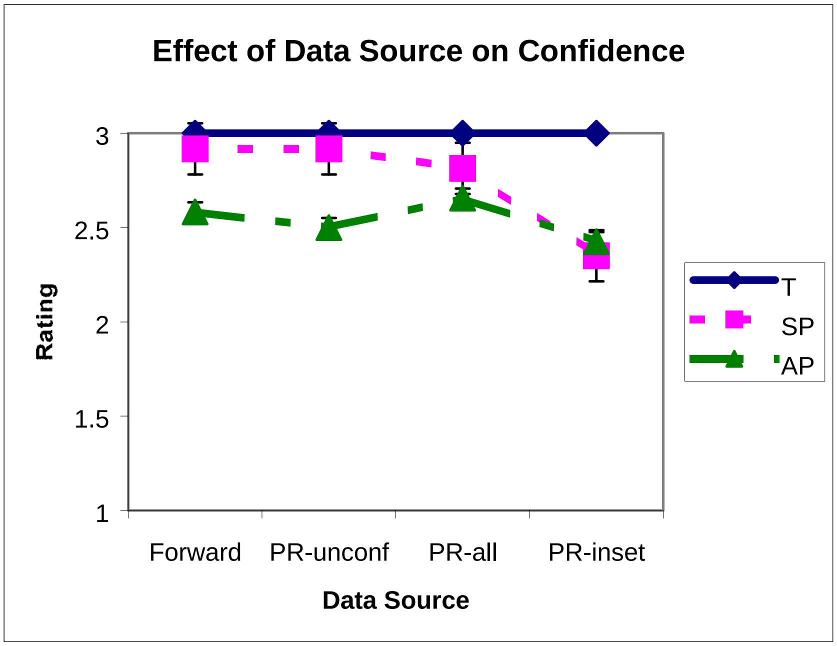


Figure R3c. Confidence ratings for enemy count questions by view condition and pan strategy, with standard error bars.

The confidence data mirrors the performance data described in Figure R3a, where T performance as well as confidence is high across all categories, while the interaction revealed the loss of confidence for the Immersed groups (and the SP group especially) on PR-inset questions, which had a corresponding drop in performance by both Immersed groups.

3.3. Calibration of Confidence

To determine how well participants were calibrating their confidence ratings to their actual performance, a 2-way ANOVA was conducted on confidence ratings for all three main question types (distance judgments, heading judgments, and enemy count) by view condition, as shown in Figure R4. There was a main effect of question type [$F(2,69)=38.17$, $p<0.01$]. Confidence was lowest for distance judgment questions, and equally high for questions on count of enemy visible as well as heading judgments.

As evidenced in Figure R1a, distance questions also produced the lowest performance, so there does appear to be some calibration of confidence to performance, although confidence in general is fairly high. The same main effect of view condition on confidence ratings seen in Figures R1b, R2b, and R3c, is evident here as well.

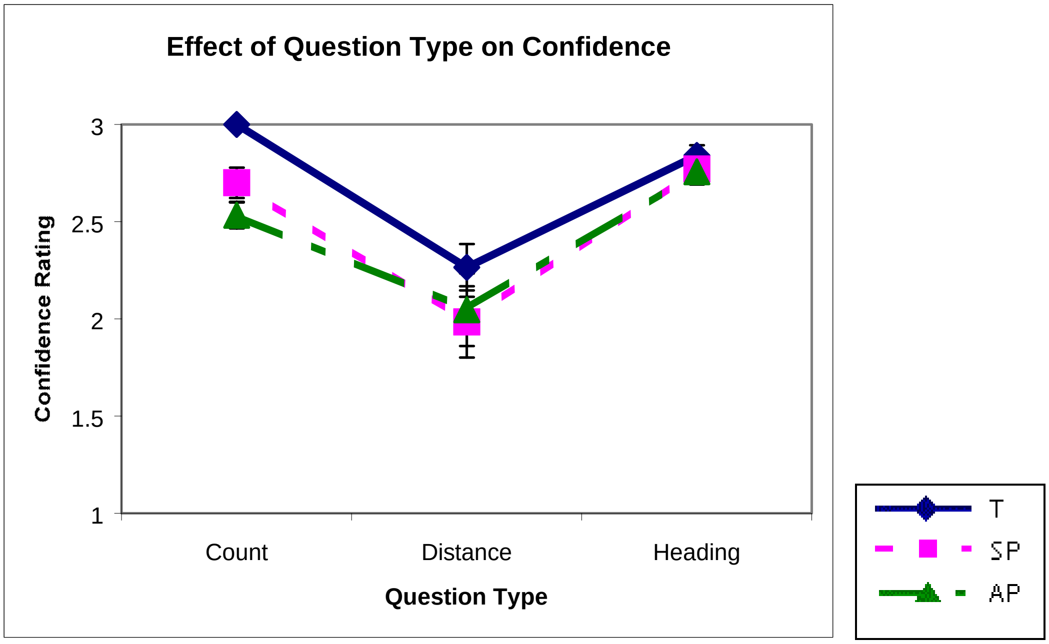


Figure R4. Confidence ratings for each question type by view condition, with standard error bars.

The interaction between question type and view condition was not significant [$F(4,67)=0.96$, $p<0.43$].

3.4. Overall Calibration of Confidence to Performance

The scatter plot of confidence against performance is shown in Figure R5. Each point reflects the data for a given question, averaged across all participants (independent of display condition). The correlation coefficient of performance and confidence ratings was significant [$r(xy)=0.585$, $p<0.01$]

Despite the fact that confidence was generally high, the positive correlation indicates that participants in all conditions were somewhat able to calibrate their confidence estimates, and rate confidence lower on questions which turned out to have less accurate performance.

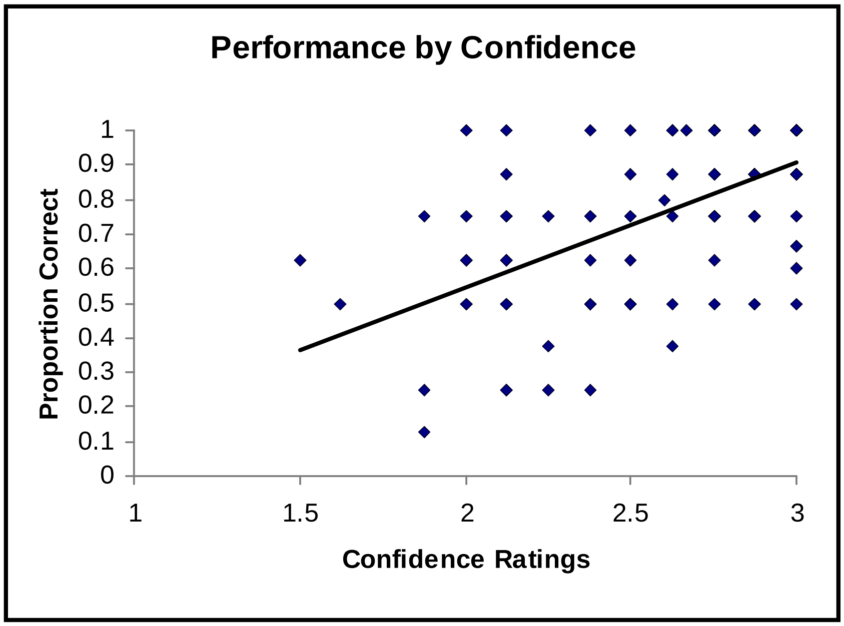


Figure R5. Scatter plot of participants' overall performance by confidence ratings.

3.5. Change Detection

There were 46 total changes to enemy icons during the course of the experiment. It was determined that 8 changes could not be reported by SP and AP participants because of the location of the enemy icon. In all 8 cases, the enemy unit itself could be seen (either partially or completely hidden by terrain features, and also visible in the 2-D inset map), but the unit's identifying letter could not be seen because of obscuring terrain or other features and thus the unit could not be identified. Since the change detection menu required a unit letter in order to record a change, those 8 unrecordable changes were eliminated from the analyses. It should be noted that since these 8 units were in fact visible, the hiding of the letter was not responsible for the lower performance on the count question. The final change (in scene 49) was also dropped from the analyses, as only one participant reported it before ending the experiment. Data from the remaining 37 changes were subsequently analyzed.

3.5.1. <u>Overall correct detections and false alarms</u>. Participants from the three view conditions correctly detected approximately three-quarters of the total number of changes (71%), but also reported various false changes. Figure R6 shows both the proportion of correct detections as well as false alarms (calculated over the total number of changes that could be detected), by view condition.

A 1-way ANOVA on correct detections revealed a significant effect of view condition [$F(2,21) = 3.44$, $p<0.05$]. T participants detected significantly more changes than did AP participants ($t_{14}=2.72$, $p<0.017$), but did not differ from SP participants ($t_{14}=0.85$, $p<0.41$). SP and AP participants did not differ significantly in number of correct change detections ($t_{14}=1.65$, $p<0.12$). In the following analyses of the change detection data, only the potential interactions of viewpoint with different levels of different change detection classification schemes will be reported.

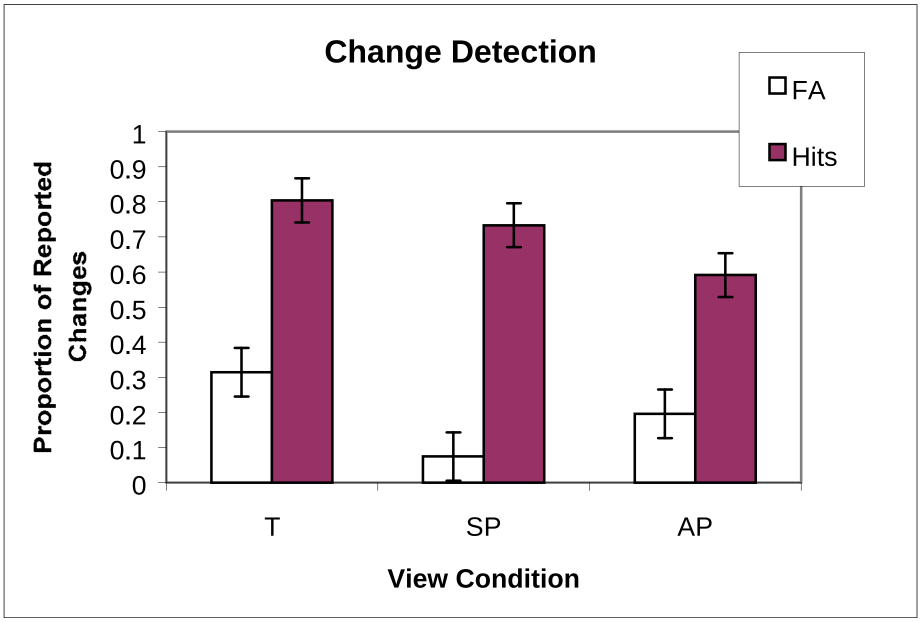


Figure R6. Proportion of correct detections and false alarms reported by view condition, with standard error bars.

Participants also reported a number of false changes. A 1-way ANOVA was conducted on the total number of false alarms per view condition, resulting in a significant effect [$F(2,21)=7.50$, $p<0.01$]. T participants reported the highest number of false alarms (avg. 11.25), which was significantly higher than the SP false alarms (avg. 2.75, $t_{14}=4.37$, $p<0.01$), but not different from the AP false alarms (avg. 7.25, $t_{14}=1.58$, $p<0.14$). SP false alarms were also significantly lower than AP false alarms ($t_{14}=2.28$, $p<0.039$).

Using signal detection theory analysis, a non-parametric measurement (the area under the ROC curve) was performed on the correct and false alarm reports by participants in each view condition to gauge overall change sensitivity. T participants produced a value of 0.75, SP participants' value was 0.83, and AP participants produced a value of 0.70. These values suggest that the number of false alarms reported is roughly equivalent to the proportion of reports provided by each view condition, which indicates that T and AP participants reported approximately the same proportion of false alarms, but SP participants were slightly more sensitive to false alarms and reported a lower proportion to total responses.

3.5.2. Type of change. The change detection data were then broken down into four categories of change type for further analysis. The four different types were: appear, disappear, change status (from unconfirmed to confirmed), and change location within the environment. The change took place either within or outside of the initial FFOV of the Immersed conditions. The breakdown of changes by type and FFOV location is shown in Table R1.

Table R1. Number of changes by type and location with respect to the initial FFOV in the Immersed conditions.

Type	Within FFOV	Outside FFOV	Totals
Appear	10	5	15
Disappear	10	4	14
Status	2	5	7
Location	0	1	1
	22	15	37

For each participant, the proportion of correctly detected changes of each type at each location (in or outside of the FFOV) was calculated, shown in Figure R7.

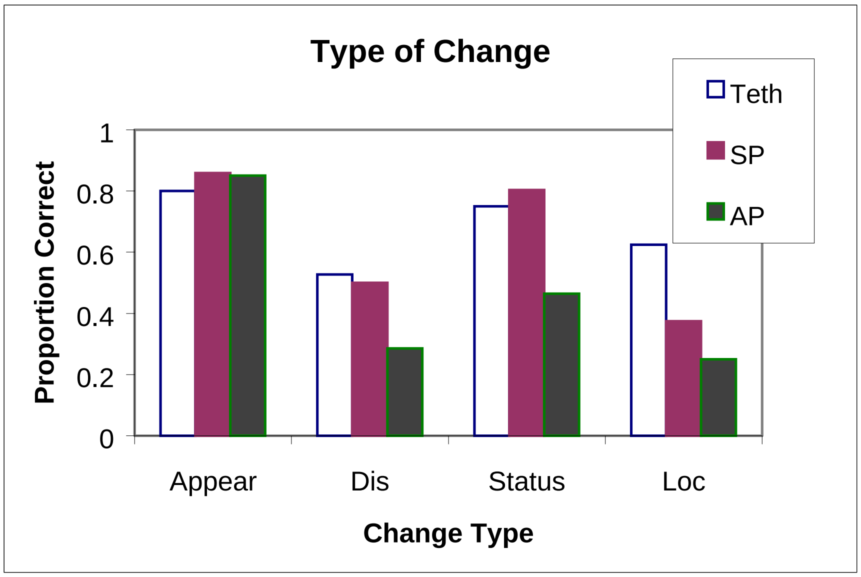


Figure R7. Change detection data for each change type, by view condition.

Since there was only one "Change Location," as noted in Table R1, this data point was dropped from further way analyses of view condition by change type and by FFOV location of change, and is discussed separately below. Figure R8 reflects the proportions of correctly detected changes for each type by view condition, without the "Change Location" data.

As noted above in the context of Figure R6, the view condition main effect was significant [$F(2,69)=5.79$, $p<0.01$], as was the main effect of change type [$F(2,69) = 22.81$, $p<0.01$]. Overall, performance was significantly better on appearance changes than on disappearances ($t_{46} = 6.91$, $p<0.01$) as well as status changes ($t_{46} = 2.62$, $p<0.012$), and status changes were reported significantly more often than disappearances ($t_{46} = 3.19$, $p<0.01$).

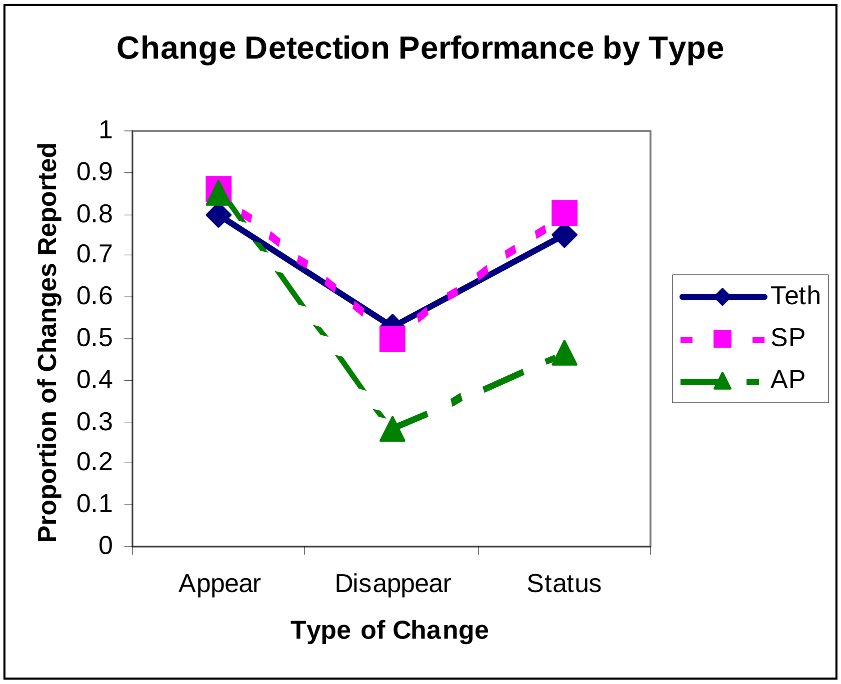


Figure R8. Performance on change detection task for each view condition by change type (omitting location changes).

AP participants performed as well as the other two groups on appearances, but clearly had more trouble detecting the more difficult change types, which accounts for the weak interaction between change type and view condition [$F(4,67)=2.00$, $p<0.105$].

3.5.3. <u>False location changes</u>. As noted above in Table R1, only one enemy unit actually changed location. As Figure R7 illustrates, on average, less than half of the participants (42%) reported seeing this change. However, three-quarters of the participants (75%) made one or more reports of false location changes throughout the experiment. In fact, false location changes composed 21.5% of T participants' false alarms, 31.8% of SP false alarms, and 44.8% of AP false alarms. It was expected that participants would have some trouble maintaining spatial awareness of objects in the environment from one scene to the next due to the loss of visual momentum despite our efforts to maximize visual momentum with increased environmental overlap between scenes.

3.5.4. <u>Location of change with respect to initial FFOV</u>. As shown in Table R1, each change was categorized as to whether it took place within or outside of the initial FFOV of the Immersed conditions. A 2-way ANOVA was conducted on FFOV location and view condition, as shown in Figure R9.

There was a significant main effect of FFOV location [$F(1,46) = 42.59$, $p<0.01$], which indicated that changes were detected significantly more frequently when they were located within the initial FFOV, an effect which was even observed in the T condition, where "initial FFOV" was not a defining property.

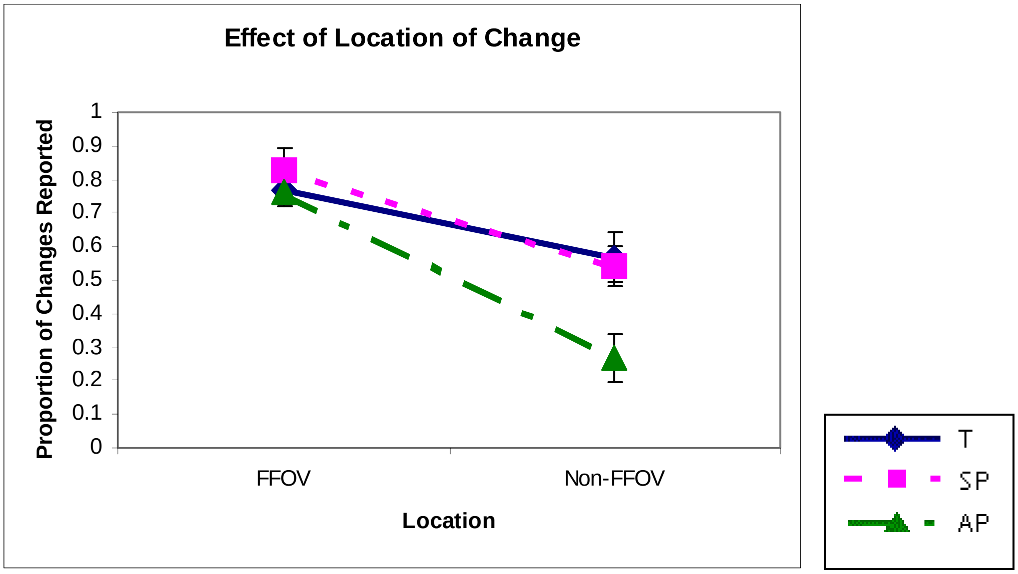


Figure R9. Effect of the location of change with respect to the initial FFOV, by view condition.

The interaction between FFOV location and view condition was marginally significant [$F(2,45)=3.03$, $p<0.06$]. This difference is accounted for by the significant decrease of the AP participants' detection performance on non-FFOV changes compared to T ($t_{14}=2.91$, $p<0.011$) and SP ($t_{14}=2.93$, $p>0.011$) participants, which were not significantly different from each other ($t_{14}=0.26$, $p<0.80$).

3.5.5. <u>Number of changes</u>. Scenes contained one, two, or three changes. The change detection was next sorted into groups depending on how many changes occurred within each scene. Several scenes were omitted from this analysis; depending on what path participants selected in Scenes 31 and 39, they were presented with one of three (Scene 32), or one of two (Scene 40), possible scenes. Each of the potential scenes contained a different number and type of changes, resulting in a variety of possible responses dependent on the scene that was viewed rather than the view condition itself. To simplify the calculations, the data from these scenes were excluded from this analysis.

Thus, these data are based on a total of 33 changes. A 2-way ANOVA was conducted on this data for number of changes by view condition, as shown in Figure R10.

There was a significant main effect of number of changes per scene [$F(2,69)=18.36$, $p<0.01$]. Although there is no difference between scenes with 1 or 2 changes ($t_{46}=1.13$, $p<0.26$), there is a significant difference between 1 and 3 changes per scene ($t_{46}=4.32$, $p<0.01$), as well as a significant difference between 2 and 3 changes per scene ($t_{46}=5.43$, $p<0.01$). The decrease in performance for the AP participants (compared to SP and T participants) in scenes with one change is accounted for by the drop in performance for non-FFOV changes from Figure R9.

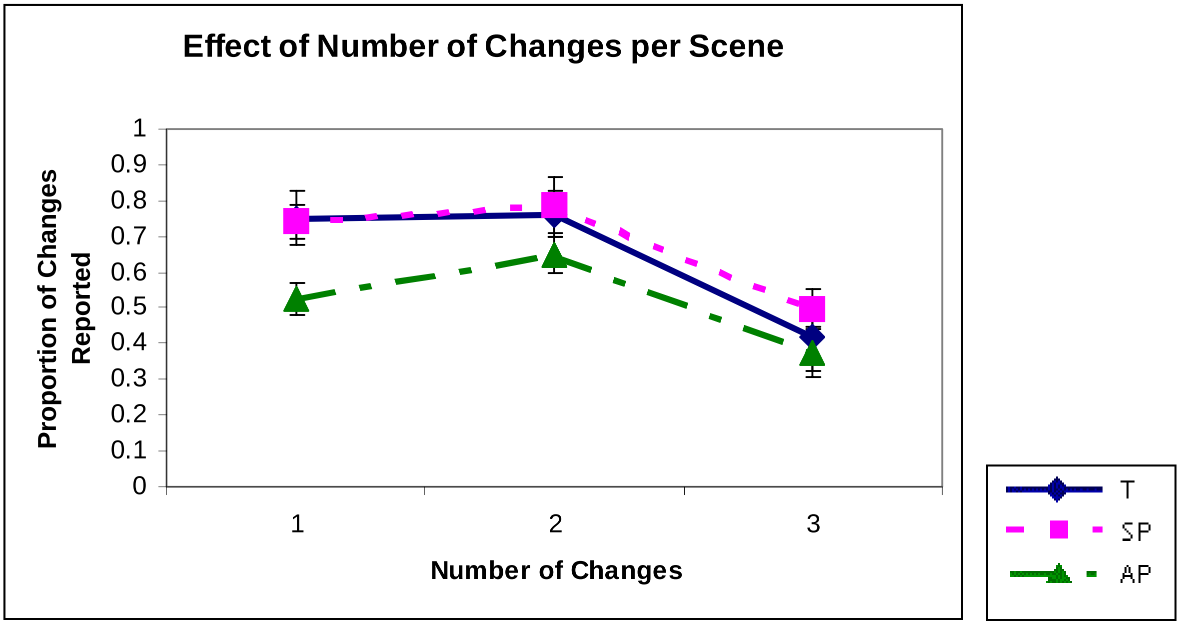


Figure R10. Change detection for different numbers of changes per scene, by view condition.

The interaction between view condition and number of changes per scene was not significant [$F(4,67)=0.52$, $p<0.72$].

3.6. Path Selection

Participants in this study were provided with two chances (Scenes 31 and 39) to select one of several path options through the environment. Since our hypothesis regarding the path selection patterns involves a comparison of the two display FORs because of their representation of vertical terrain, we have combined the information from the SP and AP Immersed conditions as "Immersed". These conditions vary only by the type of panning feature provided, not by any difference in the display FOR itself, and essentially comprise data for the same visual display. Prior to the path selection questions at Scenes 31 and 39, participants were asked to select one of three adjectives ("mountainous," "hilly," or "flat") that they felt best described the terrain. Results from this question are shown in Figure R11.

Almost all Tethered participants chose "mountainous," while all but one of the Immersed participants (both SP and AP) selected "hilly" or "flat." Tethered participants' choices were significantly different than the Immersed (Chi-Squared = 20.62, $p<0.01$)

The four questions pertaining to path selection were analyzed using a chi-square statistic. The first three path selection questions contained 3 possible paths visible in Scene 31, shown in Figure R12.

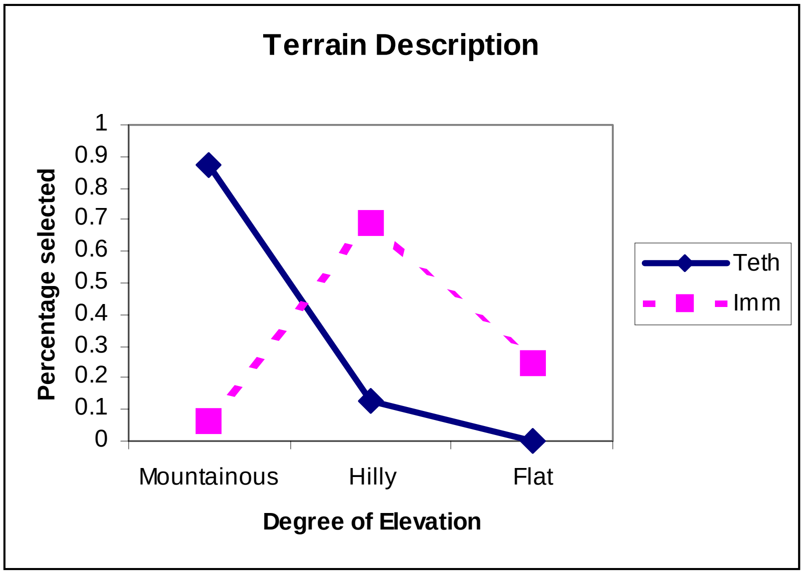


Figure R11. Selected terrain descriptions, by view condition.

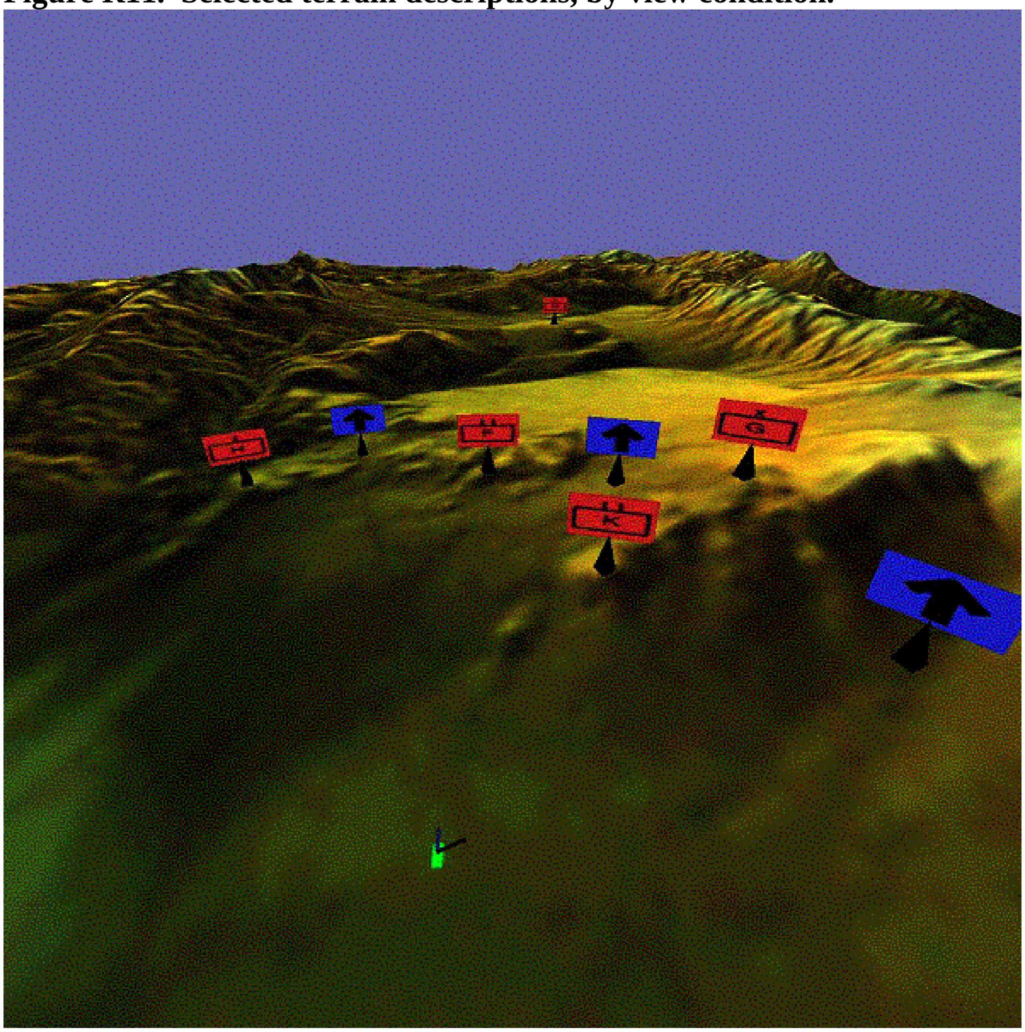


Figure R12. Scene 31, Tethered display. The three blue arrows represent the path choices through the environment.

Path 1 (leftmost arrow) led through the environment to the west in a roundabout route towards the destination (Unit M's position), through rougher terrain and some enemy threat. Of the three choices, the left path had medium terrain and a medium number of enemy units. Path 2 (middle arrow) led through the terrain to the NW on the straightest route, with flat terrain through a valley but a high number of threatening enemy units. This middle path had the easiest terrain, but the most enemy units defending it. Path 3 (rightmost arrow) appeared to lead due north on the wrong side of a small mountain ridge from the target location, but with only one enemy unit threatening it. The rightmost path had the hardest terrain to pass over, but the fewest enemy units.

Question 31 (Scene 30) was "Considering only the terrain (ignoring the enemy units), which of these arrows represents the best path to get to Unit M's position?" Results are shown in Figure R13.

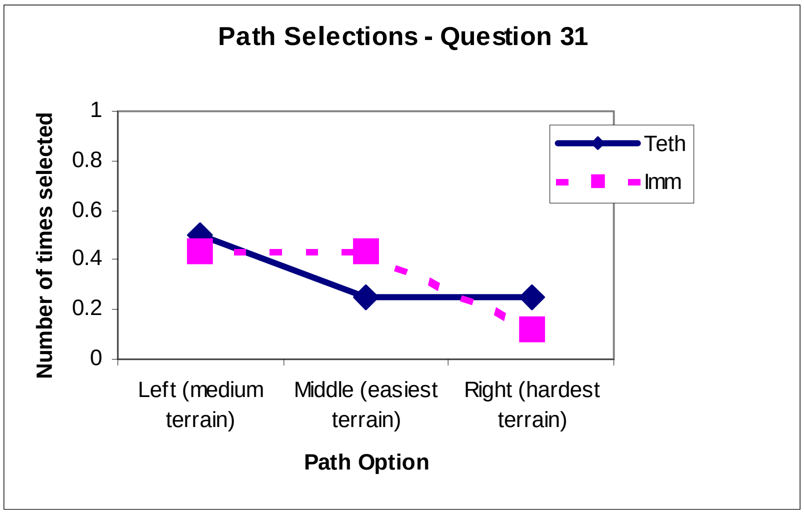


Figure R13. Path selections for Question 31, by view condition.

Analysis of the path selection results revealed that there was no difference in the selection trends by view condition (chi-square (2) = 4.12, $p<0.13$). However, both view conditions tended to select either paths 1 or 2 as the "best" path.

Question 32 (Scene 30) was "Considering only the enemy's location (disregarding the terrain), which of these arrows represents the best path to get to Unit M's position?" Results of the path selection are shown in Figure R14.

Chi-square analysis revealed a significant value (chi-square (2) = 13.12, $p<0.01$), indicating that there was a difference in path selection trends by view condition. The Tethered condition participants tended to choose path 3, which was significantly different from Immersed participants' tendency to select path 1.

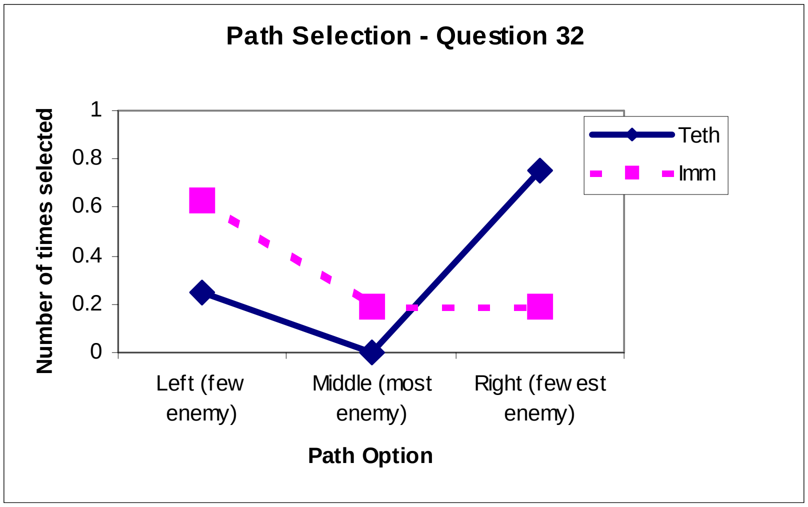


Figure R14. Path selections for Question 32, by view condition.

Question 33 (Scene 31) was "Considering BOTH the enemy units' locations and the terrain, choose the best path to get to Unit M's position." Results of this path selection question are shown in Figure R15. Whichever path the participants chose in this final question determined which of three different scenes would be viewed next (hence the different wording of the question). The three scenes corresponded to the view one would see if that path selected were actually taken. The chi-squared analysis revealed similar results to Question 32 (compare Figure R15 with Figure R14 above). Again, the majority of Tethered participants selected path 3, which was significantly different from Immersed participants' choices of paths 1 and 2 (chi-square (2) = 10.87, $p<0.01$).

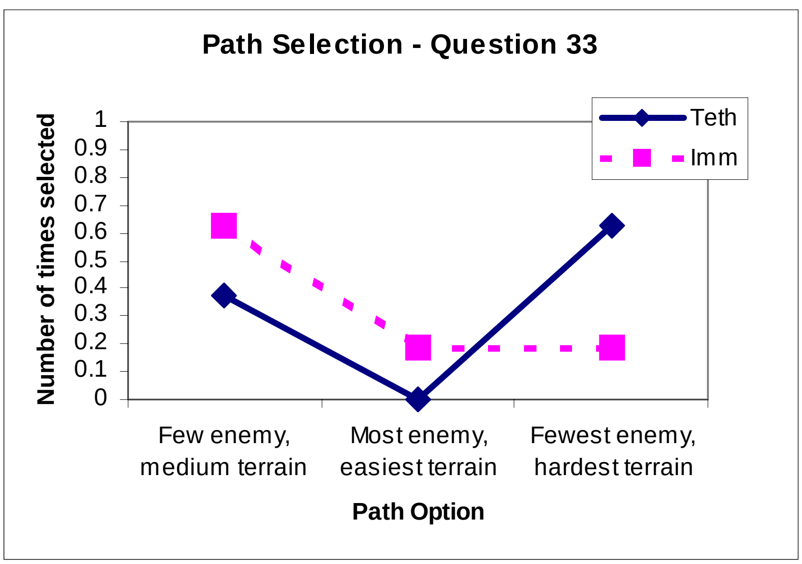


Figure R15. Path selections for Question 33, by view condition.

This indicates that the participants tended to weight enemy threat information more highly than terrain information. Tethered participants switched from preferring path 1 for the terrain-only question to path 3 in the enemy-only and terrain-and-enemy questions, while Immersed participants showed a move away from selecting path 2 (for the terrain-only question) and opted for path 3 for the enemy-only and terrain-and-enemy questions. Thus while viewpoint influenced the appearance of terrain, this appearance has no impact on path choice, which was dictated by consideration of the enemy threat.

The last path selection question (Question 41, Scene 39) was supplied with two possible paths, which are depicted in Figures M2 and M3 in the Methods section. Path 1 (left arrow) led to the west towards several enemy units on open ground. Path 2 (right arrow) led to the north along the mountain ridge, away from the enemy units to the west but close to the enemy units located behind the ridge. Both paths were on equally smooth terrain and appeared to be the same distance from the destination (Unit M's position). Question 41 was "Given how the enemy units are positioned in the environment, choose the best path to get to Unit M's position." The response to this question again resulted in one of two different scenes being presented following path selection (thus the focus of this choice was on enemy location). Results from this path selection question are shown in Figure R16.

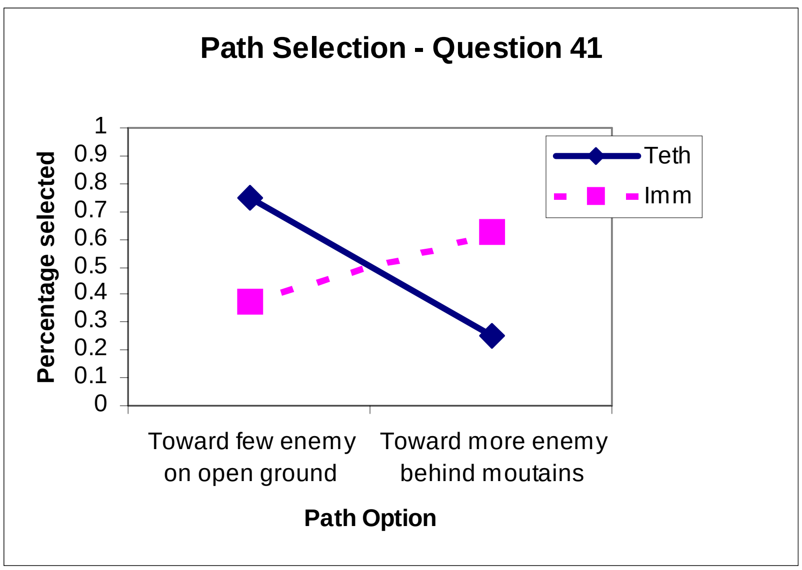


Figure R16. Path selections for Question 41, by view condition.

The majority of Tethered participants chose path 1, which was marginally significantly different from Immersed participants' tendency to select path 2 (chi-squared(1) =3.0, $p<0.08$).

In general, Tethered participants viewed the terrain as more mountainous (suggesting that terrain features were salient), but were more likely to weight enemy threat more than terrain information in making their path selections, given their response patterns in questions 31-33. In question 41, Tethered participants were faced with two paths over equal terrain, one path threatened by one enemy in open terrain and the other threatened by two enemy visible behind a mountain range, and chose the former (open terrain) path 6 times out of 8. In contrast, both

Immersed groups categorized the terrain as hilly as opposed to mountainous, indicating that the specific terrain feature relevant in this decision (the mountain range lying between the participant and two enemy units) was less salient. Yet since the “hilly” terrain obscured direct vision to the two enemy units along path 2 in question 41 (which were only visible in the 2-D map), the enemy threat was underestimated. Thus, Immersed participants were deciding between a path threatened by one enemy and a path seemingly not threatened by any enemy (unless the 2-D inset map was consulted), and chose the latter path 10 times out of 16. This effect would seem to reflect a failure to integrate information across the two views in the Immersed display, suggesting a domination of the more salient 3-D view’s FFOV.

4. DISCUSSION

The goal of this experiment was to evaluate the effects of display frames of reference on cognitive tunneling and terrain interpretation by having participants make spatial judgments and counts of enemy units, detect changes to objects in the environment, and select paths through the terrain.

4.1. Cognitive Tunneling

The results indicate that, for some conditions of some tasks, the Immersed participants’ performance suffers by comparison to Tethered participants. The patterns of results provide evidence that Immersed condition participants are anchoring to information presented in the 3-D egocentric view of the Immersed display suite; in other words, they are exhibiting display-induced cognitive tunneling. We will first review each of the four hypothetical causes proposed in the Introduction which may be responsible for causing this cognitive tunneling effect. Next, we will describe the patterns of results which support or reject each hypothesis in turn and compare these findings to the preceding study (Thomas et al, 1999). Finally, we will discuss other relevant findings as they highlight various potential difficulties with the Immersed display suite.

4.1.1. Hypothesized causes of cognitive tunneling. Before we discuss how the patterns of results fits each of the causes described in the Introduction, a brief summary of these causes, and their expected pattern of results, is presented.

1. Salience of initial FFOV information (in both of the Immersed conditions): We propose that information presented in the initial FFOV of both of the Immersed displays acquires a salience that prompts participants to trust that this information is complete and thus terminate their search for other information in the periphery. To test this hypothesis, we suggest that if both Immersed groups perform equally poorly on questions requiring information from outside the initial FFOV relative to the control T group, which has no “initial FFOV”, then salience is a major factor in determining which information is acquired, and is likely the primary cause of the cognitive tunneling effect (refer to Figure 3 in the Introduction).

2. Information Access, or response, failure: Another potential cause we propose which may be primarily responsible for the cognitive tunneling effect is the tendency of participants to conserve their efforts and reduce information access costs by limiting the search for information within the displays. As discussed in the introduction, visual scanning imposes some cost, head movement imposes greater cost, and, in many circumstances, interaction with a manual response device (such as the panning required here for the SP Immersed condition) imposes a still greater cost. The automatic panning feature was expected to eliminate the information access cost of manually panning the environment. If performance in the AP Immersed condition exceeded that of the SP Immersed condition selectively on questions requiring information outside of the initial FFOV, then information access failure is likely the cause of the cognitive tunneling effect.

3. Working Memory failure: The third potential cause of the cognitive tunneling effect is due to memory failure. We propose that if memory is the primary cause of the performance decrements, there should be an overall decrease in change detection performance from scenes with few changes to scenes with many changes to report. Additionally, with regard to the display conditions, it is likely that overall performance difference between many and few change scenes will be greater in the Immersed conditions than in the Tethered condition because objects within the Immersed conditions' 3-D view change location within the display between scenes to a greater extent than those in the T display, creating extra memory workload. That is, the two sources of memory load, more changes and sequential viewing, should negatively interact.

4. Dual-View Integration failure: The fourth potential cause of cognitive tunneling in the Immersed condition is due to a failure to accurately integrate information from the 2-D map view with that acquired from the 3-D egocentric view. We propose that if integration failure is the primary cause of the performance difference, there should be a drop in performance by both Immersed conditions for those questions requiring the integration of information that is only available from the 2-D inset map with that in the 3-D view, while Tethered performance should remain unaffected due to its single view.

For the first three hypothesized causes, we need only to look at those tasks for which all information necessary can be gathered from the 3-D view of the Immersed suite alone. To evaluate the dual-view integration hypothesis, we must also consider those tasks which require information to be gathered and integrated from both views in the suite.

Additionally, in testing these hypotheses, Salience and Information Access can both be examined by looking at both enemy count question data as well as change detection data. However, Dual-View Integration can only be evaluated by enemy count question data, because the change detection task does not require participants to integrate information from the 2-D view. Also, Working Memory can only be evaluated by change detection data since this task specifically requires remembering information from scene to scene as well as within a scene. (Enemy count questions use information which is always available within a specific scene, thus the memory workload is relatively low.)

4.1.2. Evaluation of hypothetical causes. Within the enemy count question data, there are no differences between view conditions on questions requiring information from just the initial FFOV and those requiring information from outside the FFOV **except** when the questions also require information from the 2-D inset map of the Immersed condition (refer to Figure R3a in the Results section). On these last questions, performance in both Immersed conditions drops significantly while the Tethered condition performance remains perfect. This pattern appears to best fit the Dual-View Integration hypothesis (illustrated in Figure 6 of the Introduction), suggesting that the major factor causing performance decrements in the Immersed display is the failure to accurately integrate information from both views. Immersed participants were tunneling into the 3-D view and excluding information from the 2-D map view (Olmos et al, 2000). However, to make sure that the other factors can in fact be rejected as the primary cause, we compared the pattern of actual results to the hypothesized data patterns described in the Introduction.

In evaluating the role of Salience, we compared performance on those questions requiring information from within the FFOV (Forward questions) to those requiring information from outside the FFOV (Pan-Required questions asking for unconfirmed or all enemy units). We expected to see performance for both Immersed conditions drop on the latter questions, as described in Figure 3 of the Introduction; the enemy count question data show no drops in performance, and in Tethered and SP Immersed conditions' participants perform equally well on both types of questions. Thus the location of the enemy units in or outside of the initial FFOV does not have a noticeable effect on ability to count the visible enemy units. However, in the change detection data there was an identical drop in performance for Tethered and SP participants (and an even greater drop for AP participants), from changes detected within the FFOV to changes detected outside the FFOV. Centrality of the changed object affects change detection performance, as has been found by Levin & Simons (1997) as well as Rensink, O'Regan, & Clark (1997). This suggests that, although Salience did not appear to play a role in causing performance decrements on enemy count questions, it did have some effect (on all three display conditions) on change detection ability.

In evaluating the role of Information Access, we look at the performances of the two Immersed groups on enemy count questions. Instead of the predicted advantage of the AP condition (described in Figure 4 of the Introduction), given the auto-pan feature and lack of information access cost, we find the reverse effect. The AP condition's performance is significantly lower than the SP on all categories of enemy count questions, although the pattern of performance across all four categories is nearly identical. Furthermore, SP performance is indistinguishable from the T group's performance on three of the four pan-required categories, which would not be the case if the SP participants had engaged in inadequate panning (see Figure 4 in the Introduction). Instead, the response time data show that the AP participants prematurely closed the automatic panning function, on average ending the cycle before it was completed (i.e. well before the minimum 23 seconds necessary to view the entire environment), by responding to the questions too quickly. Because of this "premature closure," information in the last 90° to 180° of the environment was rarely viewed by the AP participants, and thus any enemy units needing to be counted were not reported. Additionally, premature closure accounts for the greater drop in performance by AP participants on detection of changes outside the FFOV (refer to Figure R9 in the Results section), since some of those changes were likely never seen. Despite explicit instructions to allow the auto-pan feature to complete its cycle, as well as reassurances that there was no time limit, AP participants disrupted the panning feature anyway. It seems clear that, since no physical effort was required to manipulate the viewpoint in this condition, they were prematurely closing the auto-pan feature out of impatience or a perceived internal time cost rather than effort conservation (which underlies the information access cost implied by our hypothesis). Since AP participants show largely the same trends as SP participants in enemy count and change detection, but at a reduced performance level, we attribute this difference in performance to premature closure of the auto-pan feature.

However, this still leaves the question of whether the SP participants were affected by an information access cost. Performance data, response time data, and panning data all indicate that this was not a factor. SP participants performed nearly as well as Tethered participants on almost every task, except on those questions which required dual-view integration. Response times indicate that SP participants were taking 17.6 seconds on average to respond to the enemy count questions which required panning (over 6 seconds longer than Tethered participants), which is more than enough time, theoretically, to pan continuously through the entire environment (which takes 8 seconds). Finally and most conclusively, panning data from this condition indicate that SP participants were, in fact, actively panning the environment for the most part and thus were not engaging in effort conservation; however, it cannot be determined what percentage of the environment was viewed by SP participants, because the panning data did not distinguish between forward panning, backward panning, or pausing.

In order to evaluate the effect of working memory on performance in the Immersed conditions, we compared change detection performance on scenes with few changes to scenes with many changes for all three display conditions (see Figure 5 of the Introduction for a description of the hypothesized data pattern). We found that as the number of scenes increased over two, performance in all three viewing conditions dropped (refer to Figure R10 in the Results), suggesting that working memory does play a role in change detection (Pashler, 1988). However, there was no amplification of this effect for the Immersed conditions; the SP participants performed at nearly the same level as the Tethered condition regardless of the number of changes, and as previously discussed, the AP participants' overall lower performance can be attributed to premature closure of the auto-pan feature.

In summary, the enemy count question data show that Dual-View Integration is the primary cause of the cognitive tunneling effect, as Salience and Information Access do not appear to affect Immersed condition performance at all. When integration of information between two views is no longer a factor, Salience and Working Memory show some ability to cause cognitive tunneling, at least in terms of detecting changes in the environment (again, Information Access does not appear to affect performance of change detection). In addition, a second, unanticipated effect of premature closure (described above) appeared to be responsible for reduced performance of the AP group.

4.2. Comparisons to Previous Research

4.2.1. Spatial judgments. It was predicted that the perspective nature of the Tethered display would adversely affect distance and possibly direction judgments. This effect was observed in the studies directly preceding this research, conducted by Thomas et al (1999) and

Banks et al (1998). However, the results of the spatial judgments did not replicate those findings.

Distance judgments in the present study were poorer compared to the performance on distance estimations in Thomas et al (1999), with no significant differences found between the three display conditions (Tethered, Self-Pan Immersed, and Auto-Pan Immersed). In general, the relatively poor performance in the current study is thought to reflect the lack of map training received by the average college student (participants in the current study) as compared to military officers with 12 or more years of active service (participants in Thomas et al). However, the lack of any performance difference between the Tethered and Immersed groups was unexpected, considering that many previous studies have shown that the perspective nature of a 3-D display (e.g. the Tethered display) has a detrimental effect on distance estimation while the 2-D inset map in the Immersed suite provided veridical distance information (see Banks & Wickens, 1997, for an overview). Closer inspection of the data revealed that participants in all three display conditions (T, SP, and AP) equally under- or over-estimated the distances. This suggests that the distance questions themselves may have required too difficult discriminations for participants who are untrained in making fine distance judgments, regardless of whether they used the 1 km scale of the Tethered display or the contour map 10 km grid in the Immersed suite.

Similarly, performance on direction judgments was slightly poorer than that found in Thomas et al (1999). However, in the current experiment, the Tethered (T) condition participants made significantly more accurate judgments than those in either the Self-Pan (SP) or Auto-Pan (AP) Immersed conditions, a difference from the direction judgment performance seen in Thomas et al. It is possible that this cost relates again to those participants in both Immersed conditions concentrating more in the immersed 3-D view than on the 2-D map view to obtain their heading information.

The overall spatial judgment performance differences between this experiment and the previous one should not be surprising considering that the participants involved in this study were university students, not battle-trained Army officers well-versed with contour maps.

4.2.2. <u>Enemy count questions</u>. The overall performance on enemy count questions was higher than that seen in Thomas et al (1999). In fact, T participants scored nearly perfectly across all panning conditions, as was expected since all enemy unit information is provided at once, with no access cost other than visual scanning of the display. This increase in performance from Thomas et al (1999) could be attributed to more comprehensive instructions, which were revised after determining that T condition participants in the preceding experiments were verbally reporting enemy units but not including them in their responses to computer-based questions. The instructions for the current experiment stressed the need to perform the change detection task (which should have had the effect of prompting the participants to scan the environment for all enemy units) before responding to the computer-based questions.

Unlike previous studies which showed overconfidence in decision-making, (Cohen et al, 1997; Thomas et al, 1999), we found participants in all three display conditions to be fairly well calibrated in confidence ratings of their performance. Overall confidence ratings were high (between “Moderately Confident” and “Extremely Confident”), but showed some differentiation which corresponded to variations in performance (lower performance within a display condition resulted in lower confidence ratings). This calibration suggests that both Immersed condition participants were anchored to information in the 3-D view (though not necessarily just FFOV information) to the exclusion of information in the 2-D map view, and they were terminating their search for information and responding at lower confidence thresholds than Tethered participants (Cooper & Sniezek, 1998).

4.2.3. Change detection. Performance for all three groups was relatively high, compared to the small percentage of reported changes in Thomas et al (1999), which suggests that the change detection menu and improved instructions were successful in getting participants to attend to changes in the environment. However, in the current study there were no significant differences in change detection performance between T and SP, or SP and AP, only a significant difference between T and AP. We analyzed the data more closely to determine whether cognitive tunneling was evident in change detection performance.

4.3. In-Depth Analysis of Change Detection

4.3.1. Change type. In order to parse out participants' abilities to detect changes to objects in each of the display conditions, these changes were categorized by the types of changes (refer to Table 1 in the Results). Overall, participants detected object appearances best, followed by status changes, then object disappearances, and finally the location change. An unfortunate flaw in the program may have caused appearances and status changes to be more salient because when each new scene was presented, any objects that appeared or had changed status from the previous scene were delayed in appearing by a few milliseconds, causing a "sudden onset" effect which has been found to have the unique effect of capturing attention and increasing change detection (Jonides & Yantis, 1988). Objects that did not change from the previous scene appeared normally at the start of the scene. Thus, appearances and status changes in this experiment tended to be more easily detected because of perceptual salience, while detection of disappearances relied on the observer's ability to recall whether an object had been present in the previous scene. Performance data illustrate the effect of onset on change detection ability (refer to Figures R7 and R8). The location change also could be characterized as a sudden onset change (since it appeared slightly delayed, similar to appearances and status changes), and thus should have been as salient as the appearances or status changes, but was not detected as well as either of those two changes.

4.3.2. False location changes. Although the single object location change was only detected by 42% of the participants, the majority of participants (75%) falsely reported seeing other enemy units "move" between scenes. I suggest it is because they were primed by a) one actual location change and b) the option of "location change" as a change type. All participants who reported seeing the actual change reported at least one additional false change, indicating they were primed by one change to "see" other changes, or label a suspected change as a change in location. Also, 33% of participants who missed seeing the actual location change reported one or more false location changes, indicating that simply having "location change" as an option for the type of change being reported is enough to cause observers to use that label for a suspected change.

Because of the loss of visual momentum during scene changes, participants may not have been able to effectively track information about objects within the environment from one scene to the next. In addition, due to the relatively small 90° geometric field of view (GFOV) and lower viewpoint of the Immersed conditions' 3-D view, compared to the larger GFOV and high viewpoint of the Tethered condition, each scene change created a greater memory requirement for recalling objects in the Immersed conditions because they changed location with the display to a greater extent than in the Tethered condition. This difference is supported by the false alarm data on location changes which shows that, for the Immersed conditions, false location changes accounted for more than a quarter of false alarms (32% for SP and 45% for AP), while in the Tethered condition false location changes only accounted for 22% of false alarms. This suggests that, regardless of the raw number of false alarms reported (which was lowest in SP and highest in AP), both Immersed groups showed a greater tendency to label a suspected change as a location change than the T group. In other words, the Immersed groups did show some increased difficulty with visual momentum when compared to the T group, as predicted by the amount of extra workload required of them to track objects across scene changes.

4.4. Frames of Reference Effects on Terrain Visualization

In addition to spatial judgments, participants were asked to select a "best" path through the terrain from two or three options, based on two battle-relevant criteria, enemy location and terrain composition. The results from the two Immersed conditions were combined during the analysis since the Immersed display was the same for both conditions, and thus perception of the terrain was assumed to be equivalent between these two conditions.

4.4.1. Terrain description. Prior to the path selection tasks, participants responded to a question which asked them to describe the terrain features. Tethered participants described the terrain as mountainous, while both Immersed groups labeled it hilly (or flat). This was not surprising, since the Tethered display showed a greater amount of terrain from an angled perspective, which showed more variations in terrain (Banks & Wickens, 1997; McGreevy & Ellis, 1986), while the environment shown in the 3-D view of the Immersed display appeared significantly less variant (compare Figure M2 with M3 in the Methods section).

4.4.2. Path selection. In making the path selections, participants were first instructed to pay attention to one criteria (e.g. terrain information) and ignore the other (e.g. enemy location information), and then using both criteria select the best path to proceed through the environment towards a given destination. Neither Tethered nor Immersed participants showed any distinct choice of path when the criterion was terrain composition. The three path options may not have differed enough perceptually to give the impression that one path was substantially more vertically developed than another path. When the criterion was enemy location, however, Tethered participants tended to choose the path with the fewest enemy (which happened to be the most mountainous path) while Immersed participants opted for the path with one more enemy (and medium-textured terrain); both groups avoided the easiest path through the valley, which was guarded by the most enemy units. Finally, participants were to take both criteria into consideration when choosing the final path, and the results indicate exactly the same pattern as when participants used enemy position information alone. Tethered participants chose the path with the least enemy but most difficult terrain (potentially undervaluing the elevation information to avoid the greater enemy threat), while Immersed participants chose the path with one more enemy and moderately passable terrain. A second path choice, using both criteria, resulted in a similar decision-making pattern. Tethered participants chose a path which led directly to a single enemy unit on open ground, avoiding the path which led near the mountain range behind which were located two enemy units. Immersed participants, for whom the mountain range completely obscured those two units (which **were** visible on the 2-D map), chose the relatively safe mountain path and avoided the path leading past the enemy on the open ground. It seems unlikely that the Tethered participants would head into certain conflict along the path they chose unless they perceived the mountain range as a passable obstacle for the two enemy units behind it, increasing their judgment of the threat posed by those two units. Even if the Immersed participants did not see the enemy two units on the 2-D map (since their problem with dual-view integration has already been demonstrated), these participants provide evidence that the other path option was clearly the safer way to go.

Thus, the path selection exercise resulted in some evidence supporting the hypothesized trend of higher viewpoints resulting in reduced salience of elevation information, while at the same time creating the effect of more varied terrain features. Path selection data reveals some trends toward display frame of reference effects on terrain visualization; further research may reveal the extent to which these effects may influence real command decision-making.

5. CONCLUSIONS

This study was conducted to investigate which of several hypothesized factors were causing the cognitive tunneling effect observed in the Immersed display condition of Thomas et al (1999). Our results indicated that participants who were provided with the Immersed dual-view display were not accurately integrating information across the two views, and were in fact tunneling into the 3-D view to the exclusion of 2-D view information. The Tethered display condition appeared to support the most consistently accurate performance on almost all tasks, especially since some of the predicted problems for the Tethered view, such as imprecise spatial judgments, were not evident in this study as they were in the previous study. However, there was some evidence that the perspective nature of this display could produce inaccurate terrain visualization, and the differences in spatial judgment performance from Thomas et al (1999) as well as other research should not be ignored.

These results suggest that when creating a visual display for presenting battlefield information, the designer must balance the costs and benefits of each FOR. In both the current and previous studies, the 3-D exocentric display supported better awareness of enemy information (in terms of maintaining an accurate count of visible enemy as well as detecting changes to those enemy), but may cause officers to produce inaccurate spatial judgments about the terrain. The Army officers in the previous study were able to use the 2-D map view to make better spatial judgments about distance and direction, although neither the officers nor the students in the current study gathered any additional information from the 2-D view (such as confirmed enemy units which were not visible in the 3-D view). Clearly, although both views provide useful information about different aspects of the battlefield environment, displaying them simultaneously may not resolve these problems, as our current results indicate that participants did not access the second view's information. In addition, attempting to reduce information access costs within a single view through the use of automation did not produce the desired effect of effortless information access, as participants frequently closed it prematurely despite explicit instructions not to interrupt the feature. This may be due to some perceived internal time pressure or possibly to the fact that participants did not like the lack of control over the viewpoint.

Thus, our recommendation would be for both a 3-D exocentric view as well as a 2-D view to be available (perhaps by toggling between them), and for officers to receive training on the appropriate uses (and potential problems) with each view. For example, an officer who wants to get a general impression of the terrain and enemy numbers and locations and should consult the 3-D perspective view, but when it comes time to make decisions involving exact spatial judgments, the traditional 2-D view should be consulted since it provides the most accurate lateral information (and also can provide unambiguous, analog elevation information).

ACKNOWLEDGMENTS AND DISCLAIMER

This material is based upon work supported by the U.S. Army Research Laboratory under Award No. DAAL 01-96-2-0003. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the U.S. Army Research Laboratory.

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APPENDIX A. List of Questions

1. Which direction are you heading ?
2. Estimate the distance traveled from the previous scene.
3. How many enemy units are currently visible?
4. What type of terrain is currently in view?
5. How many unconfirmed enemy units are visible?
6. What direction is unit A from your position?
7. What direction are you heading?
8. How many enemy units are visible?
9. How many confirmed enemy units are visible?
10. Roughly what cardinal direction from your position is unit C located?
11. How close is the nearest unconfirmed enemy unit to your location?
12. How many total enemy units are visible?
13. In what direction is the nearest confirmed enemy unit?
14. How far is the nearest confirmed enemy unit?
15. How many unconfirmed enemy units remain?
16. How far is unit J from your position?
17. In what direction is unit X located?
18. How many confirmed enemy units are visible?
19. How far is unit X from your position?
20. What direction are you heading?
21. How many unconfirmed enemy units are visible?
22. How many confirmed enemy units are visible?
23. What direction is unit K from your position?
24. How far is unit K from unit G?
25. How far is unit K from unit F?
26. How many total enemy units are visible?
27. What direction are you heading?
28. In what direction is the closest enemy unit?
29. How far is unit H from your position?
30. How many enemy units are located in the pass?
31. Considering ONLY the terrain (ignoring the enemy units), which of the arrows represents the best path to unit M's position?
32. Considering ONLY the enemy units' locations (disregarding the terrain information), which of the arrows represents the best path to unit M's position?
33. Considering BOTH the enemy units' locations as well as the terrain, choose the best path to get to unit M's position.
34. In what direction are you headed?
35. In what direction are you headed?
36. In what direction are you headed?
37. In what direction is the nearest enemy unit?
38. What direction are you heading?
39. How many enemy units are visible?
40. How many enemy units are visible in the area ahead of you?

41. Given how the enemy units are positioned in the environment, choose the best path to get to unit M’s position.
42. In what direction are you headed?
43. In what direction are you headed?
44. How many enemy units are visible?
45. What direction is the closest enemy unit to your position?
46. How many enemy units are visible?
47. In what direction is the closest enemy unit?
48. What direction are you heading?
49. How far are you from unit M’s position?
50. How many total enemy units are visible?
51. In what direction is the remaining enemy unit?

NOTE: Questions 11, 30 were removed from analysis due to performance levels of less than chance for all viewing conditions. Questions 4, 31, 32, 33, 41 were categorized as subjective terrain interpretation and path selection questions (with no “correct” answer) and were exempt from performance analyses. The remaining 44 questions were categorized as follows:

Question Type Categorization:
Distance: 2, 14, 16, 19, 24, 25, 29, 49
Heading: 1, 6, 7, 10, 13, 17, 20, 23, 27, 28, 34, 35, 36, 37, 38, 42, 43, 45, 47, 48, 51
Count Questions, subcategorized by panning strategy:

- Forward: 9, 18, 22
- Pan-Required, unconfirmed: 5, 15, 21
- Pan-Required, all: 3, 8, 12, 26
- Pan-Required, inset: 39, 40, 44, 46, 50

APPENDIX B.1 Consent Form

<u>INFORMED CONSENT</u>
(BEFORE PARTICIPATION)

I consent to participate in the research entitled:

"Effects of display frames of reference on spatial judgments and change detection"

Conducted by:

Lisa C. Thomas, University of Illinois at Urbana-Champaign
Christopher D. Wickens, University of Illinois at Urbana-Champaign

My task in the research will be to view a series of computer-generated display panels depicting different evolving aspects of a movement to contact scenario. After each panel, I will answer certain questions regarding the nature of information presented.

Lisa Thomas or her representative, Liz Podczerwinski, explained the procedure and the expected duration of my participation. I am aware that although no physical or psychological harm is anticipated, I may withdraw from participating in this project at any time, without penalty. I was informed that after my particpation I will be briefed about the purpose of the research.

I acknowledge that my participation is voluntary and I will be paid $6.00 per hour (min. of one hour). I understand that the personal information I provide and the data collected will be used for research purposes only. They will be treated confidentially and will not be accessible to anyone outside the research team. A copy of this consent form may be supplied to me. If I have any questions about this research, I may contact Lisa Thomas at 217-244-4461 or Dr. Wickens at 217-244-8617.

Date: ______________________

Printed Name: ________________________________ (Subject)

Signed: _____________________________________ (Subject)

Signed by: __________________________________ (Experimenter/Data Collector)

APPENDIX B.2 Instructions for Tethered Condition

Situation Brief

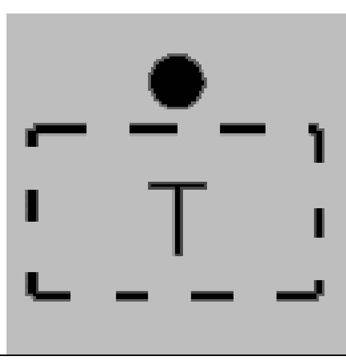
(Tethered perspective)

The research for which you have volunteered is a part of the Army Research Laboratory's Federated Lab project on Advanced and Interactive Displays, examining concepts for the future digitized battlefield. The present experiment is designed to examine some aspects of the DISPLAY VIEWPOINT for presenting battlefield information.

You are assuming the role of an Army battalion commander, in command of a mechanized/armored Task Force that is conducting a Movement to Enemy Contact. You are using a new digital 3-D map that provides visual information about the battlefield. The enemy information presented on your digital 3-D map is continuously updated by satellite imagery, information from your commanders, intelligence officers, and your troops in the field, and it will be your primary responsibility to maintain awareness of all changes and developments in the area that you traverse.

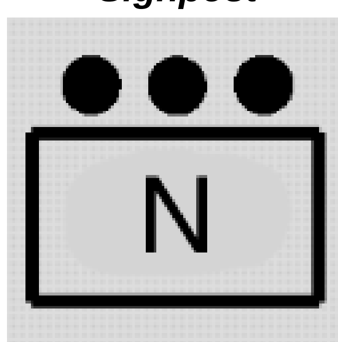
During the current operation you will track your progress by viewing a series of 50 successive scenes depicting your movement through the environment. You will know what direction your task force is heading by observing the direction that your command tank (a green box with a blue gun turret which points in the direction you're heading) is facing. There is a black line on top of your command tank that is always pointing due North, like a compass needle. This will help you stay oriented to the cardinal directions. Base ll distance or direction judgments from the location of the command tank. To assist you will distance estimates, a line of 1 KM length is shown extending leftward from your command tank's location. Your 3-D map will show you unconfirmed (suspected) enemy positions as well as confirmed (real) enemy locations. The enemy troops will be marked with red signposts which carry the enemy unit's ID letter. The enemy's real location is assumed to be at the BASE of the signpost.

Example of
Unconfirmed Enemy Signpost



Example of

Confirmed Enemy Signpost



PROCEDURE:

There are two tasks in this experiment: the first is to record any changes to the enemy units. Changes to an enemy symbol can include appearing, disappearing, changing status from unconfirmed (i.e. a dashed line symbol) to confirmed (i.e. a solid line symbol), and changing locations. Changes can be recorded by selecting the relevant (i.e. changed) enemy's ID letter and type of change from the menu to the right of the display. Click on the letter, which will remain selected, and then choose the type of change. Keep in mind that it may be important for you to remember information about previous scenes as you view successive scenes.

The second task is to answer the questions in the boxes to the right of the map display (under the menu). Please record changes before responding to the questions. Each scene will have 1 or 2 questions, asking you to make judgments about distances, directions, the enemy, etc. Please answer each question to the best of your ability, by dragging the cursor over the correct answer and clicking with the left mouse button, and then rate your confidence for the answer that you selected (ratings will be "Highly confident," "Moderately confident," or "Not at all confident"). The menu driven question format will be self-explanatory. Remember, **record any and all changes first**, and the answer the questions posed by the computer. We encourage you to offer your responses in a timely fashion, but be aware that the number of questions varies per scene, so use caution when proceeding to the next question and be sure to examine the map for changes in position, indicating a new scene.

APPENDIX B.3 Instructions for Self-Panning Immersed Condition

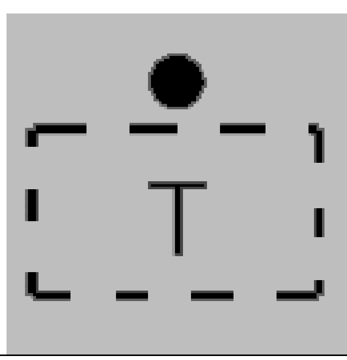
<u>**Situation Brief**</u>
(Self-Panning Immersed Perspective)

The research for which you have volunteered is a part of the Army Research Laboratory's Federated Lab project on Advanced and Interactive Displays, examining concepts for the future digitized battlefield. The present experiment is designed to examine some aspects of the DISPLAY VIEWPOINT for presenting battlefield information.

You are assuming the role of an Army battalion commander, in command of a mechanized/armored Task Force that is conducting a Movement to Enemy Contact. You are using a new digital 3-D map that provides visual information about the battlefield. The enemy information presented on your digital 3-D map is continuously updated by satellite imagery, information from your commanders, intelligence officers, and your troops in the field, and it will be your primary responsibility to maintain awareness of all changes and developments in the area that you traverse.

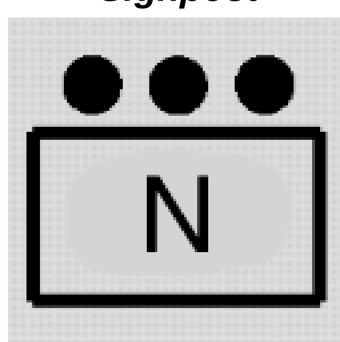
During the current operation you will track your progress by viewing a series of 50 successive scenes depicting your movement through the environment. There are two parts to this map display, a 3-D immersed view map which occupies most of the display, and a small 2-D contour inset map located at the top center of the display. The 3-D immersed view shows you the view from just above the commander's vehicle on the ground. The 3-D immersed view will show you unconfirmed (suspected) enemy positions as well as confirmed (real) enemy locations. The enemy troops will be marked with red signposts which carry the enemy unit's ID letter. The enemy's real location is assumed to be at the BASE of the signpost. You are able to interact with the 3-D immersed view by "panning" left and right. Place the cursor over the immersed view display and press either the left mouse button (to turn the view towards the left), or the right mouse button (to turn towards the right).

Example of
Unconfirmed Enemy Signpost



Example of

Confirmed Enemy Signpost



Your position on the small 2-D north-up inset map will be represented by a green circle, and your field of view is represented by a light blue “wedge.” This wedge highlights the area of the map which is shown in the 3-D immersed view below the inset map. The angle of the wedge shows the extent to the left and right that you can see: anything included within the angle of the wedge should be visible in the forward field of view unless obscured by the landscape, and anything falling outside the extent of the wedge is not visible from that position. As you pan left or right in the immersed view, the wedge will rotate in the corresponding direction on the inset map, highlighting the area of the inset map that you are now seeing in the immersed view. The initial position of the wedge also shows you what direction your task force is heading: the wedge opens up in the direction your task force is facing, and your exact heading can be determined by bisecting the angle of the wedge. This inset map will only have CONFIRMED ENEMY locations, shown as small red dots. NO unconfirmed enemy squads will appear on the inset map. Each grid on this inset map is equivalent to 10 km on a side – this is emphasized with a black bar in the center bottom of the inset map, which indicates 10 km. Roads on the inset map are in black.

PROCEDURE:

There are two tasks in this experiment. Keep in mind that it may be important for you to remember information about previous scenes as you view successive scenes, and that some highly relevant information may be located to the sides or behind you.

The first task is to record any changes to the enemy units. Changes to an enemy symbol can include appearing, disappearing, changing status from unconfirmed (i.e. a dashed line symbol) to confirmed (i.e. a solid line symbol), and changing locations. Changes can be recorded by selecting the relevant (i.e. changed) enemy’s ID letter and type of change from the menu to the right of the display. Click on the letter, which will remain selected, and then choose the type of change.

The second task is to answer the questions in the boxes to the right of the map display (under the menu). Please record changes before responding to the questions. Each scene will have 1 or 2 questions, asking you to make judgments about distances, directions, the enemy, etc. Please answer each question to the best of your ability, by dragging the cursor over the correct answer and clicking with the left mouse button, and then rate your confidence for the answer that you selected (ratings will be “Highly confident,” “Moderately confident,” or “Not at all confident”). The menu driven question format will be self-explanatory. Remember, **record any and all changes first**, and the answer the questions posed by the computer. We encourage you to offer your responses in a timely fashion, but be aware that the number of questions varies per scene, so use caution when proceeding to the next question and be sure to examine the map for changes in position, indicating a new scene.

APPENDIX B.4 Instructions for Auto-Panning Immersed Condition

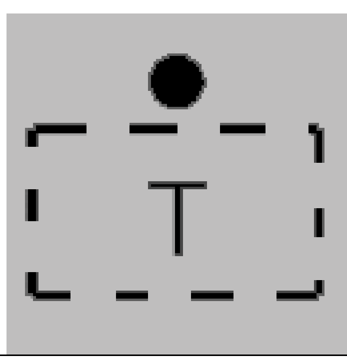
Situation Brief
(Auto-Panning Immersed Perspective)

The research for which you have volunteered is a part of the Army Research Laboratory's Federated Lab project on Advanced and Interactive Displays, examining concepts for the future digitized battlefield. The present experiment is designed to examine some aspects of the DISPLAY VIEWPOINT for presenting battlefield information.

You are assuming the role of an Army battalion commander, in command of a mechanized/armored Task Force that is conducting a Movement to Enemy Contact. You are using a new digital 3-D map that provides visual information about the battlefield. The enemy information presented on your digital 3-D map is continuously updated by satellite imagery, information from your commanders, intelligence officers, and your troops in the field, and it will be your primary responsibility to maintain awareness of all changes and developments in the area that you traverse.

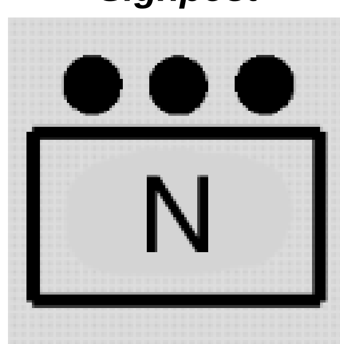
During the current operation you will track your progress by viewing a series of 50 successive scenes depicting your movement through the environment. There are two parts to this map display, a 3-D immersed view map which occupies most of the display, and a small 2-D contour inset map located at the top center of the display. The 3-D immersed view shows you the view from just above the commander's vehicle on the ground. The 3-D immersed view will show you unconfirmed (suspected) enemy positions as well as confirmed (real) enemy locations. The enemy troops will be marked with red signposts which carry the enemy unit's ID letter. The enemy's real location is assumed to be at the BASE of the signpost. Once a scene begins, there will be a 5 second pause, and then the display will automatically pan through the environment, stopping every 90 degrees for 5 seconds, and continuing on through all 360 degrees, to show you your surroundings. You will only be able to access this information once, so be sure to pay close attention to the environment as it is panned.

Example of
Unconfirmed Enemy Signpost



Example of

Confirmed Enemy Signpost



Your position on the small 2-D north-up inset map will be represented by a green circle, and your field of view is represented by a light blue "wedge." This wedge highlights the area of the map which is shown in the 3-D immersed view below the inset map. The angle of the wedge shows the extent to the left and right that you can see: anything included within the angle of the wedge should be visible in the forward field of view unless obscured by the landscape, and anything falling outside the extent of the wedge is not visible from that position. As your viewpoint pans through the 360 degrees in the immersed view, the wedge will rotate correspondingly on the inset map, highlighting the area of the inset map that you are now seeing in the immersed view. The initial position of the wedge also shows you what direction your task force is heading: the wedge opens up in the direction your task force is facing, and your exact heading can be determined by bisecting the angle of the wedge. This inset map will only have CONFIRMED ENEMY locations, shown as small red dots. NO unconfirmed enemy squads will appear on the inset map. Each grid on this inset map is equivalent to 10 km on a side – this is emphasized with a black bar in the center bottom of the inset map, which indicates 10 km. Roads on the inset map are in black.

PROCEDURE:

There are two tasks in this experiment. Keep in mind that it may be important for you to remember information about previous scenes as you view successive scenes, and that some highly relevant information may be located to the sides or behind you.

The first task is to record any changes to the enemy units. Changes to an enemy symbol can include appearing, disappearing, changing status from unconfirmed (i.e. a dashed line symbol) to confirmed (i.e. a solid line symbol), and changing locations. Changes can be recorded by selecting the relevant (i.e. changed) enemy's ID letter and type of change from the menu to the right of the display. Click on the letter, which will remain selected, and then choose the type of change.

The second task is to answer the questions in the boxes to the right of the map display (under the menu). Please record changes before responding to the questions. Each scene will have 1 or 2 questions, asking you to make judgments about distances, directions, the enemy, etc. Please answer each question to the best of your ability, by dragging the cursor over the correct answer and clicking with the left mouse button, and then rate your confidence for the answer that you selected (ratings will be "Highly confident," "Moderately confident," or "Not at all confident"). The menu driven question format will be self-explanatory. Remember, **record any and all changes first**, and the answer the questions posed by the computer. We encourage you to offer your responses in a timely fashion, but be aware that the number of questions varies per scene, so use caution when proceeding to the next question and be sure to examine the map for changes in position, indicating a new scene.

APPENDIX B.5 Post-Experiment Questionnaire

Debrief

Participant's Name: ________________________

I would like to thank you for your time in participating in this experiment. Your insight is of particular interest to me. Would you please take the time to answer a few questions? Please feel free to continue on the back for any of the questions that you need more space to reply.

1. Were the instructions clear to you as far as what you were supposed to do? Yes or No. If no, please explain.

2. On a scale of 1 to 7, how well do you feel this display would support your awareness of the evolving battlefield situation? (Circle the number)

Useless			Moderately helpful		Extremely helpful	
1	2	3	4	5	6	7

3. What was particularly helpful or what did you like about the 3-D perspective?

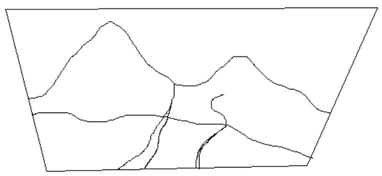
4. What was a particular hindrance or what did you not like about the 3-D perspective?

5. Is there anything that you would add to the map or displays, or other changes you would make, that you feel would improve the displays?

APPENDIX B.6 Brief Summary of Contour Map Information

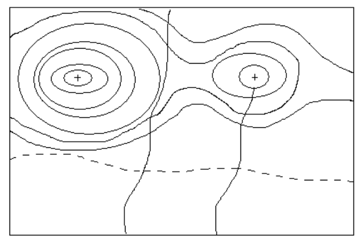
A Brief Overview of Contour Maps

Forward Field of View



Comparison

Contour Map



1. Contour maps show terrain elevation using lines.
2. A high point in the terrain (a hilltop or mountain peak) is shown as a series of concentric circles.
3. A mountain pass or valley is shown as a set of concave lines which bow in toward each other OR as the space between two sets of concentric lines
4. Lines which are spaced very close together show increased steepness of the hillside or mountainside.
5. Lines which are spaced far apart show flat terrain
6. Higher terrain is marked with more concentric lines, lower terrain has fewer lines

Circle the number which most closely reflects your ability to correctly read and interpret contour maps:

Very Poor	**Moderate**	**Very Good**
(this was all new to me)	(I remember some from school)	(I'm very familiar w/ contour maps)

1 --------- 2 -------- 3